

A Contemporary Approach to Expressiveness  
in the Design of Digital Musical Instruments

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# Abstract

Digital musical instruments pose a number of unique challenges for designers and performers. These issues stem primarily from the lack of innate physical connection between the performance interface and means of sound generation, for the latter is usually dematerialised. Thus, this relationship must instead be explicitly determined by the designer, and can be essentially any desired. However, many design issues and constraints remain poorly understood, from the nature of control to the provision of performer-instrument feedback.

This practice-based research contends that while the digital and acoustic domains are so different as to be fundamentally incompatible, useful antecedents for digital musical instruments can be found in the histories of electronic music. Specifically, it argues that the live electronics of David Tudor are of particular prescience. His home-made circuits offer an electronic music paradigm quite antithetical to both the familiar keyboard interface and the electronic music studios that grew up in the years after World War II, and are seen to embody a number of aspirational qualities. These include performer-instrument interaction more akin to steering rather than fine control, the potential for musical outcomes that are unknown and unknowable in advance, and distinct instrumental character.

This leads to the central contribution of this research; the development of a Tudor-inspired conceptual framework that can inform how digital musical instruments are designed, played, and evaluated. To enable more detailed and nuanced discussion, the framework is broken down into a series of sub-themes. These include both design issues such as nuance, plasticity and emergence, and human issues such as experience, expressiveness, skill, learning, and mastery. The notion of sketching in hardware and software is also developed in relation to the rapid iteration of multiple designs.

Informed by this framework, seven new digital musical instruments are

presented. These instruments are tested from two different perspectives, with the personal experiences of the author supplemented with data from a series of small-scale user studies. Particular emphasis is placed on how the instruments are played, the music they can produce, and their capacity to convey the musical intentions of the performer (i.e. their expressiveness).

After the evaluation of the instruments, the Tudorian framework is revisited to form the basis of the conclusions. A number of modifications to the original framework are proposed, from the addition of a dialogical model of performer-instrument interaction, to the situation of digital musical instruments within a wider musical ecology. The thesis then closes with a suggestion of possibilities for future research.

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# Glossary

AM – amplitude modulation

Arduino – an Open Source microcontroller and associated software environment

BCI – Brain-Computer Interface

CC – Creative Commons

CEMAMu – Centre d'Etudes de Mathématique et Automatique Musicales (Paris)

CETL – Centre for Excellence in Teaching and Learning

CHI – ACM SIGCHI Conference on Human Factors in Computing Systems

CO<sub>2</sub> – carbon dioxide

CNMAT – Center for New Music and Audio Technologies (at Berkeley)

CCV – Community Core Vision

DI – diffuse illumination

DIY – do-it-yourself

DoF – Degrees of Freedom

EEG – electroencephalography

FFT – Fast Fourier Transform

FM – frequency modulation

FTIR – Frustrated Total Internal Reflection

GRM – Groupe de Recherches Musicales (Paris)

GUI – Graphical User Interface

HCI – Human-Computer Interaction

HID – Human Interface Device

IDM – Intelligent Dance Music

IO – Input/Output

IR – infrared

LDR – light dependent resistor

LED – light emitting diode

Machinima – the use of 3-D video game engines to create cinematic films

Max – MaxMSP/Jitter software

MEV – Musica Elettronica Viva

MIDI – Musical Instrument Digital Interface

NIME – New Interfaces for Musical Expression

NUI – Natural User Interface

OSC – Open Sound Control

PA system – public address system

PAR – Practice as Research

PBR – Practice-based Research

Pd – Pure Data

PLL – phase locked loop

PlOrk – Princeton Laptop Orchestra

RCA – Royal College of Art (London)

RDF – Resource Description Framework

RSS – RDF Site Summary

SD – standard deviation

SHF – something to hold onto factor

STEIM – Studio for Electro Instrumental Music, based in Amsterdam

TEI – Tangible and Embedded Interaction

UPIC – Unite Polygogique Informatique du CEMAMu

USB – Universal Serial Bus

VNS – Very Nervous System

VR – Virtual Reality

WDR – Westdeutscher Rundfunk (Cologne)

# Chapter 1

## Introduction

### Personal Background and Motivations

Through engagement with theoretical discourse and the development of practical proofs of concept, this research explores how digital musical instruments can be better understood and designed. In doing so, it aims to establish a platform for future developments in what remains a relatively youthful and immature field. With hindsight, this topic can be considered a favourable match for my personal background, for I have been interested in music and technology from an early age. At age six, for example, I began to study the trumpet, and soon after the acoustic and electric guitar. Then, aged nine, I learned to write simple computer programs on my father's desktop computer. My teen years saw me become immersed in avant garde art and music. I thus went on to study sonic art at the University of Northumbria, before a chance relocation to Coventry saw my current practice take shape under the auspices of composer Rolf Gehlhaar. This is focused on the design and implementation of both digital musical instruments and interactive sound environments. While distinctions between the two are sometimes blurred, the former are explicitly intended for performance use, while the latter are intended for less formal play. Since 2009 my practice has evolved due to ill health. Less able to cope with the physical demands of live performance, I have become primarily a creator of instruments intended for others to play. This unplanned and unexpected change is inevitably apparent in this work.

# Terminology

For those who come to digital musical instruments from an arts background (myself included), terminology can represent a particular challenge. While real-time musical interaction with computers has been explored in a variety of fields, substantial differences in vocabulary have hampered interdisciplinary discussion and debate. Thus, before this thesis continues further, key terminology will first be outlined. This includes fundamental definitions of:

- Tudorian;
- digital musical instruments;
- music and musical performance.

As will soon become apparent, the American pianist and live electronics pioneer David Tudor is of central and pivotal importance to this research. Thus, in this context, the term "Tudorian" refers to the Tudor-inspired thought that underpins both the written thesis and practical portfolio.

Of equal importance is the term "digital musical instruments". To deconstruct the term further, if the prefix "digital" is perhaps the most contestable aspect, there are at least two reasons it is applicable to the instruments presented in the practical portfolio (see Chapter 4). Most obviously, they are built around computers and microcontrollers, and are therefore principally and materially digital in nature. Also, the planned obsolescence that characterises mainstream digital culture (Fino-Radin, 2010)<sup>1</sup> plays a role in their development, for as Phil Archer (2004) notes, this is often what makes previously unaffordable technologies become available to hackers and artists. What is more, if the ubiquitousness of the term "digital" lends it an undesirable vagueness, possible alternatives are already claimed for other purposes, for example "hybrid" (Mathews and Moore, 1970), "computer-based" (Moody, 2009),

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<sup>1</sup> David Nye (2006, pp. 135-159) offers a useful extended critical discussion of technology and sustainability.

and "post-digital" (Richards, 2006). The simple prefix of "new", meanwhile, is not only too closely tied to the New Interfaces for Musical Expression (NIME) conferences to allow for much critical distance, but perhaps also too suggestive of a naïve clamour for novelty.

What constitutes a musical instrument in the digital context is similarly contestable and contested. On the one hand, Marcelo Wanderley (2001) posits that a digital musical instrument consists of sensor input (performance interface) and sound synthesis (output), joined by a (software) mapping (see Hunt and Wanderley, 2002; Hunt, Wanderley and Paradiso, 2002; Levitin, Mcadams and Adams, 2002; Marshall, 2009; Murray-Browne *et al.*, 2011). A similar model is proposed by Niall Moody (2009). In both cases the implication is that a musical instrument is more than any one component in isolation; in other words, it is a balanced construction. Bert Bongers (2006), on the other hand, privileges the interface (i.e. the boundary between performer and instrument) as the most important part of the instrument. Indeed, as Sergi Jordà (2005) and Mark Marshall (2009) assert, in the NIME community the terms interface and instrument are often used interchangeably (i.e. the term instrument is used to describe an interface). The definition adopted here is most similar to that proposed by Wanderley (2001), with the following exceptions. Firstly, the instrument model is extended to incorporate sound diffusion and the provision of feedback to the performer. Second, the boundary of the instrument is considered more diffuse and permeable, and has the potential to extend out into its environment (i.e. an instrument environment). This can be related to the surf metaphor for live electronics offered by Ron Kuivila and David Behrman (1998), where everything done with a surfboard in the surf is part of surfing.

In order to define musical performance, it is reasonable and perhaps necessary to first attempt to define music itself. While some extremely elaborate definitions have been proposed (e.g. Xenakis, 1991), music is considered here in perhaps the most concise and open terms possible, as simply the sound output of the instrument or instruments in question. The definitions of music as organised sound (Cage, 1973)

and wanted sound (Austin, 1998) are also useful reference points. At this point an open-ended definition is seen to be appropriate, for new instruments may foster unexpected new music (Jordà, 2005), and additional restrictions may inadvertently hinder their emergence.

The same applies to notions of musical performance. Stan Godlovitch (1998, p.13), for example, defines performance in terms of a culturally-loaded public activity, primarily concerned with the conveyance of expression. He contrasts this with the notion of playing. Closely related to practice, playing is not only considered to be more private and insular, but primarily concerned with the development of technical skills. However, this distinction makes little sense in the context of this research, for it is desirable to maximise the opportunities to test the instruments created. Thus, the term performance is defined and used more generally, to refer to both the act of playing a musical instrument and, in the sense of Giovanni De Poli (2004), any performance issues raised.

Additionally, while musical performance is traditionally often considered in terms of deviation from a predetermined (i.e. composed) score, Michael Gurevich and Jeffrey Treviño (2007) insist that it is not desirable to apply this model to the digital instrument context:

It is correspondingly reprehensible to suggest that electronic music practice can be made more expressive by adhering more closely to a conventional text/act model, i.e. by fostering multiple unique interpretations of the same text in order to clarify the "expressive difference signal" between text and act: In addition to arbitrarily conflating comparative evaluation with the perception of expressive performance, this prescription insists that praxes change in order to align with hegemonic theoretical models and values. (Gurevich and Treviño, 2007, p. 109)

Crucially, appropriate texts (scores) have yet to be written, for as John Cage (1937)

and Jordà (2005) assert, new instruments can both inspire and benefit from new musical texts. While these may emerge over time, the main concern of this initial stage is to discover and explore the possibilities of the new instruments created (and therefore new texts may subsequently be written). Thus, more open-ended models and understandings are required of both performance and related issues. While useful antecedents are found in improvised music (Bailey, 1992; Munthe, n.d.), recent work by Gurevich and Treviño (2007) may be particularly pertinent. In the absence of a score (or similar text), the authors argue that additional information is needed in order to assess more elusive issues such as expression and expressiveness. They therefore propose a relational model that considers the interactions between actors and artefacts in a wider system that "includes external factors such as genre, historical reception, sonic context and performance scenario" (Gurevich and Treviño, 2007, p. 9).

These definitions lay the foundation for this thesis to now continue. However, the issues raised will be revisited in subsequent chapters, and Chapter 3 in particular.

## **Background to the Research**

To generalise greatly, contemporary musical performance practices based on and around digital technologies tend to fall into three broad categories:

- digital musical instruments and interfaces;
- the unadorned laptop plus custom software (i.e. laptop performance);
- post-digital instruments (a lo-fi reaction to the above [e.g. Richards (2006)]).

With some notable exceptions (e.g. Weinberg, 2002; Gehlhaar, 2006), the digital musical instruments and interfaces category tends to maintain the conventions of traditional (i.e. acoustic) musical instruments (Jordà, 2005; Armstrong, 2006;

Marshall, 2009). Since 2001, the main outlet for this work has been the NIME conference series, but it has also featured elsewhere, for example at the interdisciplinary Tangible and Embedded Interaction (TEI) (Mann *et al.*, 2011) and Audio Mostly (Lympouridis, 2009) conferences.

By contrast, both laptop music performance and post-digital instruments eschew the established traditions of musical instrumental and related conventions.<sup>2</sup> Thus, albeit in radically different ways, they present performers and audiences with unfamiliar sounds and interactions. While this thesis (to some extent) takes issue with all three paradigms, its principal argument is that, in their acoustic instrument foundation, existent approaches to digital musical instruments stymie (and perhaps even harm) their development, and thus that new approaches are desirable and needed. That the acoustic instrument paradigm stubbornly persists is perhaps unsurprising. For thousands of years, almost all cultures have actively participated in the design and playing acoustic musical instruments (Paradiso, 1997; Hermann and Hunt, 2005). As a result, humankind has not only mastered controllable and expressive sound production via acoustical means, but also become extremely familiar with the sounds produced by these performer-instrument interactions (Merrill and Raffle, 2007). Thus over an extended period of time, specific expectations (particularly of sonic causality) have developed, some of which have become culturally engrained (Cascone, 2000).

Meanwhile, like the industrial exploitation of electricity itself, electric and electronic instruments are a comparatively recent development (Hunt, 1999). Despite this, their rapid adoption and subsequent popularity has meant that after little more than a century, their forms have become well established and their possibilities extensively explored. Indeed, they have played a pivotal role in 20th century music and popular music in particular (Sinker, 1995).

Computers by contrast have existed for around 60 years. However, early computers were not only prohibitively expensive, room-sized machines, but also

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<sup>2</sup> There are some systems that blur the categories, for example recent work by Mike Gao and Craig Hanson (2009).



incapable of real-time audio processing (Hunt, 1999; Wang, 2008) and therefore fundamentally ill-suited to the demands of musical performance (Roads, 1996; Chadabe, 1997, p. 120; Gehlhaar, 2002; Jordà, 2005; Marshall, 2009). Thus, until the personal computing revolution of the 1980s, computers for musical use remained primarily the preserve of well-funded institutions and a small number of do-it-yourself (DIY) enthusiasts (Brown and Bischoff, 2002). While the desktop computers of the 1980s could do MIDI processing in real-time (Hunt, 1999), it was the release of the Apple PowerBook in the 1990s that revolutionised real-time audio creation and manipulation (Cascone, 2002). Moreover, the subsequent development of the (real-time) musical computer has taken place within the increasingly rapid social and technological change characteristic of the late 20th century (Kurzweil, 1999, pp. 30–32). With entire categories of technology prone to appear and disappear in only a few years (Fino-Radin, 2010), the potential for sustained exploration can be limited not only by the inclination of designers and performers, but also the availability of replacement parts.

This problem of experience (or lack thereof) is additionally compounded by the fact that knowledge accumulated in the acoustic domain is not readily transferable, for the differences between acoustic and digital instruments are substantial. Acoustic instruments for example transduce performance gesture directly into sound, and are notable for their one-to-one correspondence between input and output. From the perspective of the audience, it is clear that the sound produced emanates from within the body of the instrument. However, the sonic possibilities of acoustic instruments are relatively inflexible,<sup>3</sup> determined primarily by the design of the interface and sound production mechanism, and the materials from which they are made.

Digital musical instruments meanwhile do not innately transduce the gestures or movements of the performer into sound. This relationship is instead mediated by a computer, and must be actively designed. Such is the flexibility afforded that this relationship can be essentially any. The same flexibility is found in the area of sound

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<sup>3</sup> For example, a piano cannot sound much like a trumpet.

production; software algorithms can produce almost any sound imaginable (Jordà, 2005). It can be argued that this chameleon-like quality leads digital musical instruments to possess little character of their own. Additionally, these sounds are often projected from external loudspeakers rather than from inside the instrument (Harris, 2006). For Pedro Rebelo (2006), the resultant loss of haptic sensation brings the previously intimate performer-instrument relationship to an abrupt end.

A similar notion is explored by Marshall (2009). He states that while acoustic instruments present a physical resistance that the performer must overcome in order to produce sound, the situation in digital musical instruments is quite different. Digital instruments he suggests are able to incorporate sensors that are so easily actuated that the performer-instrument interaction can appear effortless.<sup>4</sup> This creates a potential conflict, for after thousands of years of exposure to the acoustic instrument paradigm, effort has not only come to be expected, but often considered a prerequisite of expression (Ryan, 1991; Waisvisz, 1999).

Physical effort is a characteristic of the playing of all musical instruments. Though traditional instruments have been greatly refined over the centuries the main motivation has been to increase ranges, accuracy and subtlety of sound and not to minimize the physical. Effort is so closely related to expression in the playing of traditional instruments. It is the element of energy and desire, of attraction and repulsion in the movement of music. But effort is just as important in the formal construction of music as for its expression: effort maps complex territories onto the simple grid of pitch and harmony. And it is upon such territories that much of modern musical invention is founded. (Ryan, 1991, p. 10)

In the conspicuous absence of effort, the consequent gap between expectation and the performance experience provides ample opportunities for misunderstanding and misinformation. This has led to the perpetuation of half-truths and rumours, for

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<sup>4</sup> If a Brain-Computer Interface (BCI) is used, interaction may be entirely without (apparent) physical effort.

example that:

and while he was doing that he'd logged his tax return electronically!

(Cascone, 2002, p. 56)

Nevertheless, if it is apparent that the literature often considers digital instruments in terms of decline or loss, these concerns are principally valid only if digital instruments are held up to the qualities of their acoustic predecessors. While this thesis emphasises that the two are not directly comparable,<sup>5</sup> it could equally be argued that, with previously imposed restrictions dissolved and replaced by barely bounded possibility, digital instruments in fact afford enhanced opportunities. Without the need for the performance interface to act physically and directly on the sound generation mechanism (Marshall, 2009), almost any arbitrary combination of the two is possible. The problem is that if all combinations are not equally successful, the most productive combinations are poorly understood, and (beyond the simple imitation of acoustic instrument forms) few authors agree as to how digital musical instruments should be designed. As Jordà (2005) notes, the current structure of the field is perhaps a contributory factor. On one side there is the NIME community. Their work is typically heavily biased towards the performance interface (e.g. Cook, 2001; Huott, 2002; Patten, Recht and Ishii, 2002; Lyons, Haehnel and Tetsutani, 2003; Newton-Dunn, Hiroaki and Gibson, 2003; Mann *et al.*, 2011; Chun *et al.*, 2010; Hayes, 2010; Marier, 2010; Taylor and Hook, 2010; Yamaguchi *et al.*, 2010; Yerkes, Shear and Wright, 2010). On the other side there are those involved in sound synthesis and digital signal processing (e.g. Bank and Karjalainen, 2010). Their interests are more fragmented and diverse, and only some of those involved are dedicated to instrumental (real-time) applications. With little cross-participation or dialogue between the two sides (Jordà, 2005) collage-like, mix-and-match approaches to digital instrument construction have prevailed (e.g. Maruyama *et al.*, 2010). This

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<sup>5</sup> In the same way that a Bach harpsichord concerto and a track by Autechre or The Aphex Twin cannot be easily compared.

juxtaposition of different and sometimes disparate elements manifests itself in instruments that tend to provide inconsistent and (in more extreme instances) incoherent experience.

Thus, rather than better interface designs or interfaces designed conjointly with (Moody, 2009) or to reflect the means of sound production, it is necessary to consider the entire instrumental experience. To develop a coherent digital musical instrument experience relates closely to the metaphor offered by Behrman:

everything done with a surfboard in the surf is a part of surfing. Of course, not everyone is an equally accomplished surfer. (Kuivila and Behrman, 1998, p. 14)

In the context of this research, this metaphor can be reframed as:

that done with a digital musical instrument + that experienced as a result of  
a digital musical instrument = digital musical instrument design

This notion of consistent and coherent instrumental experience is omnipresent in this research. It is discussed more fully in subsequent chapters. Nevertheless, inconsistent design and experience is not the only issue, for it is equally problematic that current digital instruments so often imitate the familiar forms of their acoustic predecessors.<sup>6</sup> This relates to the interface being no longer directly involved in sound production. Correspondingly, where once the performance gestures associated with these interfaces were necessary to produce sound, in digital instruments they are redundant. While their continued presence in digital instruments may be passed off as a harmless concession to the safely familiar, it is important to remember that the designers of acoustic instruments have often compromised human and ergonomic aspects for the sake of acoustic ones (Jordà, 2005; van der Linden *et al.*, 2011). By contrast, the

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<sup>6</sup> This is the case even when, like Marshall (2009) and Moody (2009), this is intended to create coherent digital instruments.

design freedoms afforded by digital instruments raise the possibility of interaction developed around the needs and capabilities of the human body.

What is more, this imitation of traditional schemes of interaction has hindered the development of a distinct identity for digital musical instruments. One way to develop this is to emphasise those possibilities that are specific or sympathetic to the digital medium. For Nick Collins (2003; 2006), the potential to create unpredictable outcomes through the use of generative systems is one such possibility:

Live computer music is the perfect medium for generative music systems, for non-linear compositional constructions and for interactive manipulation of sound processing. [...] Generative music has a capacity for greater subversion of memory and greater thrills of unknowability. (Collins, 2003, pp. 67–73)

However, while generative systems are well established in related musical domains such as live coding and computer-aided composition, they are found in few of the instruments presented at NIME since 2001. Instead, designers have tended to favour fixed structures and mappings more like those found in acoustic musical instruments.<sup>7</sup>

When all this is taken into account, it is possible to identify the following dichotomy. On one hand, digital musical instruments are not yet sufficiently understood for designers to exploit their full potential (Ryan, 1991). On the other hand they are fundamentally (and perhaps irreconcilably) different from their acoustic predecessors, and previously accumulated knowledge is not readily transferable. By offering a more coherent and characterful approach to digital instruments, this research hopes to move the field at least a few steps forward. The approach proposed draws on the seminal works of live electronics created by Tudor (Gray, 1999). It is hoped that, as examples of systems that radically depart from the traditional instrumental paradigm yet also involve the performer, striking a balance between predictability and unpredictability, and exploiting the full potential of their medium

<sup>7</sup> Even if, as previously asserted, the two kinds of instruments are fundamentally incompatible.

(Covell, 2003), they will provide useful foundation upon which to build this research.

## **The Hypothesis and Research Questions**

In short, humankind has created acoustic instruments for millennia. While these instruments are by no means perfect, almost all cultures have become vastly experienced and skilled in their design and performance. However, the digital musical instrument domain is so dissimilar to the acoustic one as to be fundamentally incompatible, and much prior knowledge is not directly transferable to the digital instrument context. Thus, alternative approaches are needed if the potentials of digital instruments are to be fully exploited. Within the unbounded possibilities of the digital domain, a primary challenge is how to balance the different and sometimes disparate needs of the performer (over the short and longer-term), the instrument (its character and output), and expressive musical performance.

Against this backdrop, this research hypothesises that the live electronics of Tudor may offer a more appropriate and productive foundation upon which to base our understanding of digital musical instruments. In other words, the Tudor electronics may help critically to consider and discuss digital instruments, and aid their design. This hypothesis informs the following research questions:

- How is prior and current art in the field deficient, and how does it fail to meet the demands of performers and performance?
- Which qualities and characteristics are desirable in digital musical instruments, and which aspects of previous (acoustic/electric/electronic) instruments should be maintained and discarded?

In particular:

- Can a Tudorian framework help to understand digital musical instruments, and aid in their design?
- What can be discovered about the digital musical instruments created by playing them, and how might these findings apply more widely?

Within these research questions it is possible to see where new knowledge may be produced and applied. The exploration of these questions pervades this research, and they are explicitly revisited and reconsidered in the final chapter to provide the basis for the conclusions. To help direct and steer the research, a series of aims and objectives have been developed. These are to:

- examine critically the digital musical instruments field, so as to challenge and build upon its established theories, methods, and practices;
- develop a conceptual framework that can both help to critique established musical instruments, and also aid the design of new ones;
- informed by the framework, design and implement a number of new digital musical instruments;
- test and evaluate the new instruments, and, by proxy, the framework itself;
- place the outcomes and findings of this research within the wider digital musical instruments field, and make a contribution to its debates.

As this research project passes each of these intermediary steps, the reader is reminded of the comment of Perry Cook (2001), that this kind of work often moves forward as more art than science, and this may be the only way it can be done.

## Overview of the Tudorian Framework

At the heart of the research is a Tudor-inspired conceptual framework. Its central premise is that the live electronics of Tudor can not only help to understand digital musical instruments, but also aid and inform their design (i.e. the framework performs a dual role). Informed by Jordà (2005), the framework is broken down into a series of sub-sections to enable more nuanced discussion. These are:

- Emergence
- Nuance
- Skill and skilling
- Plasticity and meta-plasticity
- Expression, expressiveness, and spectacle
- The human turn
- (The nature of) experience
- Long-term engagement, learning, and mastery

Emergence concerns how musical instrument designs evolve over time, and how performers both adapt to and actively shape them. Nuance is concerned with the limitations of established digital musical instrument design practices. It argues that they continue to be either excessively narrow (expert instruments for specific virtuosos) or broad (musical toys for complete novices), and that more nuanced approaches are required. Skill and skilling considers how the skills needed to play digital musical instruments are often fundamentally dissimilar to those demanded by their acoustic predecessors. Plasticity relates to how digital musical instruments are able to change their shape drastically, often on-the-fly, and the effect this has on instrumental character and identity. Expression, expressiveness, and spectacle considers the sometimes problematic relationship between expression and visual



spectacle in the context of digital musical instruments. Most crucially, it makes a distinction between expressive gesture (which is quantifiable) and expressive intention (which is subjective), and another between necessary and theatrical gesture. The human turn considers how a return to musical instruments (compared to, for example, the clerical laptop performance paradigm) is intrinsically also a return to the human, and associated qualities such as accident and error. These are then related to notions of effort and spectacle discussed earlier in the framework. (The nature of) experience considers the moment-to-moment experience of playing a digital musical instrument. It argues that the notion of flow (commonly applied to acoustic instrument performance) is a poor fit for the digital musical instrument context, and the Situationist notion of the *dérive* is proposed as a more appropriate alternative. The final part of the framework, long-term engagement, learning, and mastery, is concerned with what it means to engage with a digital musical instrument over extended periods of time. In particular, the concept of mastery is re-drawn for the digital musical instrument context.

It is important to note that the framework does not attempt to dictate the design of digital musical instruments, nor impose hard rules or inflexible design guidelines. It instead tries to provide a series of interconnected elements as an aid to thinking through issues of key importance. These range from how the instrument is designed and the nature of the performer-instrument relationship, to the exploration of its musical possibilities and the potential for learning and mastery in this new context.

## **The Practice-Based Nature of the Research**

Christopher Frayling (1993, pp. 1–5) defined practice-led research as research into art, research through art, or research for art. In the years since this definition, the nature of research has continued to be the subject of much interest and debate (Lyons, 2006), and a number of closely related but distinct terms have emerged. These

include practice as research (PAR) (Pakes, 2004), practice-based research (PBR), practice-led research (Candy, 2006), and the more specific performance as research (Kershaw, 2009). Linda Candy (2006), for example, makes a distinction between research that includes a creative artefact as the basis of the contribution to knowledge, and research that leads primarily to new understandings about the nature of practice. In the first instance, she suggests, the research is practice-based, while in the latter instance it is practice-led.

Certain aspects of both types can be identified within this research. On one the hand, the artefacts produced may contribute to knowledge. They tell us more than was previously known about a certain kind of digital musical instrument. On the other hand, the research may also lead to new understandings about the nature of practice. The most crucial difference is perhaps that the portfolio is an integral part of the work, and therefore the results of this research are not able to be fully described in text form alone. Thus, according to the above distinction the notion of PBR is the most appropriate, and the one adopted here.

This PBR may initially appear to take place at the boundary of multiple disciplines (Mansilla, Dillon and Middlebrooks, 2000) and therefore be inherently interdisciplinary. Indeed, it is eminently possible to identify intersections between fields as diverse as computer science (Collins, 2003; 2006) and media arts (Archer, 2004; Grierson, 2005), HCI (Hunt, 1999; Marshall, 2009) and more traditional musical performance (Paradiso, 2011). However, over the last decade, digital musical instruments have become established as a distinct (if not yet mature) field. In addition to the growth of the NIME conference series (2001 to present), this shift is enabled by and apparent in key texts by Wanderley and Marc Battier (2000) and Eduardo Miranda and Wanderley (2006), Ph.D. theses by Gil Weinberg (2003), Jordà (2005), Mick Grierson (2005),<sup>8</sup> Collins (2006), Newton Armstrong (2006), Marshall (2009), Moody (2009), and Pete Bennett (2010), and curriculum design (D'Arcangelo, 2002).

Marshall (2009) proposes that this development of digital musical instruments

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<sup>8</sup> Note that this example is a practice-based Ph.D.

as a singular area of activity is necessary and essential, for the technical, musical, and performative demands they place on participants would not otherwise often be considered complementary or developed together. This is closely related to my own background, where these skills were developed approximately simultaneously. Thus, for this research to treat digital musical instruments as a distinct field is not only sympathetic to current trends, but also a natural fit for my practice.

## **Roadmap of the Research Project**

This introductory chapter concludes with two roadmaps. The first outlines the subsequent chapters of this written thesis, while the second offers an overview of the practical portfolio. While the written and practical aspects can be enjoyed separately, they are intended to be experienced together so that each can support and add value to the other.

### **The Written Thesis**

Following this introduction (Chapter 1), the written thesis is organised into four further chapters. Chapter 2 initially surveys the evolution of musical instruments since the introduction of electricity (i.e. the period 1870–2012), thereby setting the context of this research. The live electronics of Tudor are pivotal, providing a critical lens through which subsequent developments can be examined and exposed. After exploration of its histories and antecedents, the chapter hones in on the digital musical instrument field and the instruments presented since 2001 at the NIME conferences in particular, and offers an overview of their anatomy. The diversity of these instruments is seen to typify the fragmented, pick-and-mix approaches to design

mentioned earlier in this introduction. Informed by this survey, the second half of the chapter proposes a Tudor-inspired conceptual framework as an aid to understanding and designing digital musical instruments. Loosely linked by notions of expression and expressiveness, the framework includes concepts of emergence, nuance, skill and skilling, plasticity and meta-plasticity, spectacle, the human turn, the nature of (the instrument) experience, and long-term engagement, learning, and mastery. Where applicable, these concepts are related to my own experiences as a designer and performer.

Chapter 3 sets out the methodological basis of the research and details its methods. Particular attention is paid to its practice-based nature, and to the relationship between theory and practice more generally. The first half of the chapter deals with the methods used in the conception, design and implementation of the portfolio instruments. The second half of the chapter then focuses on the methods used to test and evaluate these instruments. In order to assess their more intangible and subjective qualities, a multi-faceted approach is adopted (i.e. mixed methods). Moreover, it is hoped that by combining multiple perspectives, a more rounded understanding can be developed.

Chapter 4 presents and discusses the practical portfolio. This consists of seven new digital instruments informed by and developed out of the Tudorian framework. Therein theory is turned into practice, and practice is grounded in theory. The instruments are presented on a case-by-case basis with personal reflection (from the perspective of the designer-performer) supplemented with feedback from users who took part in a series of small-scale studies. Following discussion of each individual instrument, an attempt is made to consider how the findings are related and connected. The final part of the chapter makes a case for Drone (the last of the iPad Topographies) to be the most successful instrument in the portfolio, for its balance of simplicity and depth of possibility, directness and subtlety is seen best to embody the concepts proposed in the framework.

Chapter 5 begins with a summary of the thesis so far, then reconsiders the

initial research questions in order to draw a series of conclusions. As part of this process the framework is re-evaluated and ultimately revised. The chapter closes with an explicit statement of the contributions made by the research to knowledge and practice, and a more speculative suggestion of possibilities for future research.

## **The Practical Portfolio**

The practical portfolio documents seven new digital musical instruments, plus a selection of earlier and related work (see Fig. 1). The portfolio is housed on a dual-layer DVD that accompanies this thesis. It will play in any DVD player or computer. The code for each of the instruments can be found in a data partition on the same DVD.



Fig. 1. The portfolio DVD, main menu.

The primary contents of the portfolio are as follows:

- **Scanners** is a digital musical instrument marrying an off-the-shelf Brain-Computer Interface (BCI) to a custom mapping layer and three exemplary musical patches. All three patches are generative/semi-generative, and each explores a different model of mapping and sound generation;
- the **mTABLE** is a home-made multi-touch table built from readily available components, plus four accompanying musical topographies. These explore a range of tactics, from on-the-fly sampling of environmental sounds, to an interconnected quartet of virtual instruments, loosely based on the Karplus-Strong algorithm;

- the **iPad Topographies** are a series of five musical topographies for the Apple iPad multi-touch tablet. They are derived, at least in part, from the earlier mTable work, and therefore represent a continuation of the same ideas and themes.
- the **ServoString** is a hybrid digital/robotic instrument in which generative processes guided by the performer actuate an array of tuned string units;
- **Vanishing Point** employs the built-in webcam and computer vision techniques to extend the reach of the laptop to encompass whole body interaction;
- inspired by neural networks, the **DelayNet** instrument is a collection of interconnected but initially empty pockets that the performer, through their gesture motions, fills with environmental sound;
- considered here as a meta-instrument, the **Eden3** system translates into music the physiological experience of a plant as it responds to its environment in real-time.

At various points in this thesis the contents of the portfolio DVD are referred to directly, to illustrate specific remarks and claims. These references are enclosed in parentheses, and take the form of: (see DVD example: video title: subtitle: chapter number). For example: (see DVD example: iPad Topographies: User Study: chapter 4). The reader is referred to Appendix A for specific details of the DVD chapters.

Two of these projects in the portfolio directly involve the contributions of others. The ServoString instrument was initially conceived as a collaboration with Gehlhaar during the winter of 2008–9 but the project soon forked and the instrument was pushed in different directions. The Gehlhaar version combines few, relatively complex string units with simple controls and software mappings. The version presented here has more, relatively simple string units, with indirect controls and more complex software mappings inspired by brain-like *The Connection Machine* supercomputer (Hillis, 1985, pp. 18–22). The Eden 3 project, meanwhile, was initiated by the environmental artists Tim Collins and Reiko Goto in 2008. They were

joined a few months later by agricultural scientist Trevor Hocking, computer scientist Carola Boehm, and me. The project is highly interdisciplinary and encompasses not only musical but also scientific and educational issues (Collins, Goto and Hocking, 2009). My primary contribution is the design and implementation of the real-time musical system, including programming and composition realised in Pure Data (Pd) and MaxMSP/Jitter (Max), and the modification of the hardware at an electrical level to enable real-time operation.



# Chapter 2

## Towards a Tudorian Framework for Digital Musical Instruments

### Overview

The initial focus of the chapter is the enduring consequences of the introduction of electricity to musical instruments more than a century ago. Based on the accounts of David Dunn (1992), Curtis Roads (1996), Joel Chadabe (1997), Andy Hunt (1999), Gehlhaar (2002), and Thom Holmes (2008), among others, particular attention is paid to the effect on musical instrument design and performance in the 20th and 21st centuries. No claim is made to offer an exhaustive historical record, but while there has been a focus on the performance interface and the performer-instrument relationship elsewhere, a concerted attempt is made here also to include issues of mapping and sound generation. Throughout, the primary concern is to identify what has been lost and gained, and what may yet be discovered.

The initial period surveyed spans some 70 years, from the innovations of the Telharmonium, theremin, and Ondes Martenot, to the unpredictable live electronic circuits of Tudor. The latter are seen to embody a number of desirable characteristics, and are adopted as a lens through which subsequent developments, many of them seminal, can be considered, discussed and critically evaluated. These include commercial analogue synthesisers by Robert Moog (1965) and Donald Buchla, the widespread adoption of the Musical Instrument Digital Interface (MIDI) protocol, and the first dedicated interfaces for real-time computer music. Only then are more recent developments surveyed, with an informal, anatomically-led tour of the digital musical instruments presented since 2001 at the NIME conferences followed by a

critical overview of two parallel practices. The first, often called laptop music performance, is revealed to be a spread of practices linked by performance issues related to their reliance on clerical models of interaction. The second is what John Richards (2006) terms "post-digital" instruments, or a return to the handmade and analogue in the face of dissatisfaction, at least in some quarters, with what is considered to be the indirect and excessively pristine nature of computer-based music.

Informed by qualities identified as salient and desirable (earlier in the chapter), the second part develops a Tudor-inspired framework that can both help to understand digital musical instruments and also aid their design. The intention is not rigidly to dictate the forms of digital musical instruments, but instead to provide more flexible points of departure for discussion and design. Informed by Jordà (2005), so that more focussed discussion can take place, the framework is broken down into a series of smaller (but often intertwined) aspects that are considered in turn. These are:

- Emergence
- Nuance
- Skill and skilling
- Plasticity, meta-plasticity
- Expression, expressiveness, and spectacle
- The human turn
- (The nature of) experience
- Long-term engagement, learning, and mastery

Throughout the discussion, particular attention is paid to the need for an adjusted (i.e. non-traditional) understanding of notions such as learning and mastery (when dealing with these kinds of digital musical instruments).

## Early Developments

Music plus electricity equals the sound of the 20th century (Schillinger, in Sinker, 1995)

While the likes of the Jesuit priest Jean Delaborde had conducted musical experiments with static electricity in the mid-18th century (Davies, 2004), it was not until the end of the 19th century that electronic instruments arrived in earnest (Dunn, 1992). Spurred, at least in part, by the new communication technologies of the period, many novel instruments were developed in the space of only a few years (Hunt, 1999; Holmes, 2008, pp. 3—44). These include the Electronic Telegraph (1876), Singing Arc (1899), Chorelelo (1906), and Telharmonium (1906).

The trouble about these beautiful, novel things is that they interfere so with one's arrangements. Every time I see or hear a new wonder like this I have to postpone my death right off. I couldn't possibly leave the world until I have heard this again and again. (Twain, in Weidenaar, 1995, p. 139)

The Telharmonium measured 30 feet in length, weighed 200 tons, and featured 145 individual rheotomes or simple oscillators (see Fig. 2). As the above quote from Mark Twain implies, the experience of it must have been unprecedented and extraordinary for audiences of the time. Due to its massive heft, the machine was obviously ill-suited to live performance. Instead, it piped its output to listeners across a city-wide network that anticipated the development of Muzak in the 1940s (Castleman, 1996).

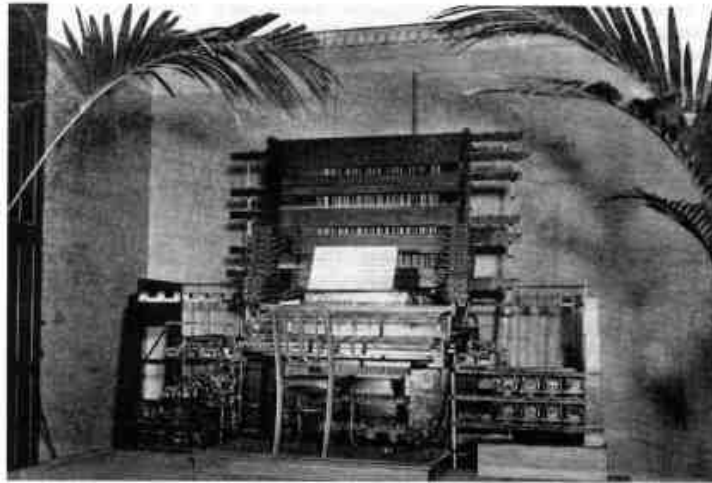


Fig. 2. The Telharmonium (1897) (Wikipedia, 2010a).

While the service-orientated business model of the Telharmonium was ultimately unsuccessful, due largely to legal action brought by telecommunications operators, some of its features were ahead of its time (Hunt, 1999). These include the provision of two polyphonic, pressure-sensitive keyboards and the ability to combine the outputs of multiple rheotomes (Weidenaar, 1995, p. 31; Hunt, 1999).

Following the invention of the Audion tube by Lee De Forest in 1906, it was used by Russian inventor Lev Termen (later Theremin) to create the theremin in 1919 (see Fig. 3). The first non-contact instrument, its performance interface consists of one vertical rod and one horizontal loop (Glinsky, 2000, p. 51; Holmes, 2008, pp. 19–20). In this arrangement, the hand of the performer acts as the grounded plate of a variable capacitor. The capacitance value is determined by the distance of the hand from the antennae. Thus the performer is able to control the pitch and amplitude of a single oscillator by moving their hands in relation to the antennae.

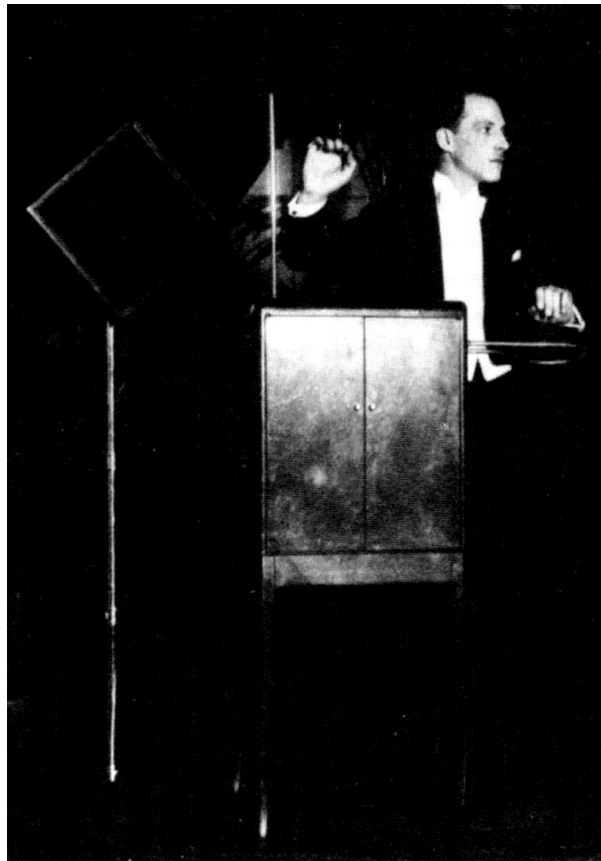


Fig. 3. A young Léon Theremin playing a theremin, c. 1924 (Wikipedia, 2010b).

However, while its performance principle is easily understood, the theremin is often considered one of the most difficult instruments to learn and play well (Hunt, 1999). This is due to the emphatic absence of haptic feedback and visual reference points. The performer is therefore forced to rely on his/her ear in order to play in tune, and listening skills are often poorly developed in beginners (Letowski, 1985; Kraus and Chandrasekaran, 2010). In short, the freedom offered to the performer by the theremin interface may actually impede the expressive potential of the instrument.

Going beyond these design issues (i.e. aspects that may be controlled by the designer), the theremin also offers a reminder that less predictable cultural issues can also impact on the fortunes of musical instruments:

When Theremin provided an instrument with genuinely new possibilities, Thereminists did their utmost to make the instrument sound like some old

instrument, giving it a sickeningly sweet vibrato, and performing upon it, with difficulty, masterpieces from the past. Although the instrument is capable of a wide variety of sound qualities, obtained by the mere turning of a dial, Thereminists act as censors, giving the public those sounds they think the public will like. We are shielded from new sound experiences.  
(Cage, 1937)

Although for many people the innovative design of the theremin has come to symbolise the freedoms of electronic music (and perhaps modernism more generally), electronic instruments increasingly returned to the more familiar chromatic, organ-type keyboard as their means of control.<sup>9</sup> The interwar period in particular saw a flood of new electronic keyboard instruments (Hunt, 1999). These include the:

- Electrophon (1921);
- Staccatone (1923);
- SuperPiano (1927);
- Dynaphon (1928);
- Ondes Martenot (1928);
- Givelet (1929);
- Trautonium (1930);
- Hammond Organ (1934);
- Electronic Sackbut (1937).

It is certainly curious that novel interfaces should so quickly be discarded, and some authors go as far as to suggest that this failure to move beyond the keyboard significantly stifled the development of electronic music (Hunt, 1999; Miranda and Wanderley, 2006). However, if the return to the keyboard might generally be considered a timid and perhaps even retrograde step, there are at least some examples

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<sup>9</sup> See Jean Perrot and Norma Deane (1971) for a comprehensive account of the musical keyboard.

of innovation within the keyboard context.



Fig. 4. The Ondes Martenot (THEfunkyman, 2007).

The once-popular Ondes Martenot (see Fig. 4), for example, adds an additional layer of continuous control to the traditional keyboard interface (Davies and Orton, 2001). The performer first puts their index finger through a metal ring, then moves their hand side-to-side in order to produce continuous changes in pitch (Hunt, 1999). Adding to its versatility, the performer is able to play the keyboard concurrently, or to use either method in isolation. Moreover, although its performance principle is (arguably) more complex, the tactility of the Ondes Martenot interface makes it (compared to the non-contact interface of the theremin) easy to play well, while still supporting performer virtuosity (Dunn, 1992; Holmes, 2008, p. 27). Despite these differences in interaction, it is important to note that the instruments (in their original forms at least) have identical timbral limitations, for both utilise a single sine wave

oscillator. While the sound of the Hammond Organ, developed only a few years later, is certainly richer and more complex, the instrument was not an instant success. Intended to be a portable replacement for the pipe organ in churches, its distinctive sound took until the 1960s to find its place in popular music, by which time electronic sound had become considerably more established.

Despite these differences, the theremin, Ondes Martenot, and Hammond Organ all maintain the traditional relationship of input to output, whereby the instrument produces a direct response to each gestural input (Castagne *et al.*, 2004). This may be most problematic in the case of the theremin, for there is a clear disconnect between the novelty of the interaction and the traditional mapping strategy. This split instrumental personality creates a potential conflict of expectation and is a possible source of harm to the performer-instrument relationship.

## Temporal Machines

The technological advances of World War II were applied to electronic music in the late 1940s, thereby providing foundation for the electronic music studio of the 1950s (Hunt, 1999). These included the Groupe de Recherches Musicales (GRM) in Paris, the Westdeutscher Rundfunk (WDR) studio in Cologne, and the Columbia Tape Music Center in the United States. While Michel Chion and Guy Reibel (Dack, 2002) emphasise that the GRM composers did not consider the studio to be an instrument, the centre produced numerous innovative instrument-like devices (Poulin, 1999; Manning, 2004; Emmerson, 2007, p. 150). These include the:

- morphophone: a looping device with feedback;
- pupitre de relief: a system for moving sounds around a multi-channel loudspeaker system;



- phonogène: a tape-based precursor of the sampler.

The phonogène is of particular interest in the context of this research due to its exploitation of possibilities specific to the tape medium. According to Jacques Poulin (1999), three different versions were developed:

- chromatic phonogène: constrained playback speed to the discrete pitches of the keyboard;
- sliding phonogène: used a control rod to provide continuous variation of tape speed;
- universal phonogène: provided the ability to vary pitch and time independently.

The materiality of the gramophone record allows one to cut, to skip, to retard, accelerate and reverse, but only as variations in an already predetermined form, in a record that has always already been cut. As many have observed, the importance of tape lies in the fact that it allows many more opportunities to interrupt, intervene in and to transform the signal as it is being formed. (Connor, 2010)

Temporal manipulation (and dislocation) is a key characteristic of tape as a medium (Dunn, 1992; Dack, 2002), and similar ideas were widely explored elsewhere. For example, in his pioneering work on granular sound, the British physicist Dennis Gabor, proposed both kinematic (non-mechanical) and electrical (non-mechanical) methods of time-distortion (Opie, 1999). While the electrical method was not implemented, three kinematic systems were developed. The first two systems used a modified film projector and sound film, but the third system used magnetic tape like the phonogène. Its closed tape loop enabled an infinite cycle of record, playback, and erase (Opie, 1999). This led to the Tempophon or Springermaschine; a commercial machine developed by the Springer company that found favour in some German

studios during the late 1950s (Roads, 1996, p. 441). Interestingly, both the phonogène and Tempophon have recently been revisited. Makenoise (2011)<sup>10</sup> created a new (hardware) version of the phonogène, while Tom Erbe (2010), influenced by the Tempophon, developed the pitch delay (software) plugin. These do not try to imitate the original machines as such, but instead to distil their essential characteristics into more contemporary digital forms. They are seen to exemplify a similar kind of updating to that proposed by this research.

## Live Electronics

If tape-based machines<sup>11</sup> such as the phonogène and Springermaschine are closely tied to the electronic music studio,<sup>12</sup> a more performative take known as live electronics evolved in parallel. Like many 20th century musical tropes, the work of Cage was a formative influence (Nyman, 1999). While his *Imaginary Landscapes* of 1939 provided a direct and literal model for subsequent praxis (Hunt, 1999; Deakin, 2009), Cage also offered the basis for a more general enabling methodology:

[I]n creating electronic music instruments, the builder is in fact simultaneously acting as post-Cagean composer by simultaneously constructing a highly restrictive collection of limitations and an indeterministic set of performance possibilities, each full of as much potential and risk as the builder/composer wishes to allow the performer. (Holzer, 2011)

Nevertheless, it was Tudor – a close collaborator of Cage – who provided the main impetus for the field, having essentially withdrawn from the piano to work almost

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10 A contemporary US synthesiser module manufacturer not associated with Pierre Schaeffer or the Groupe de Recherche de Musique Concrète.

11 I hesitate to call them instruments.

12 It is not the intention of this research to downplay the impact of the studio on subsequent music.

exclusively with electronics (Dunn, 1992; Chadabe, 1997, p. 81–89; Pritchett, 2004). Whereas tape required that music be precisely constructed and assembled (outside the time frame of performance), the Tudor circuits provided and emphasised the ability to create electronic sound spontaneously (i.e. in real-time, during the time frame of the performance).

[I]t was his desire for the unpredictable and unique that inspired his in-depth study of the principals of amplification and feedback. By returning part of the output of a circuit back to its input, essentially creating an electronic loop, Tudor could generate new sound entirely through electronic means. This principle is known as feedback oscillation. (Gray, 1999)

A consistent feature of the Tudor electronics is the use of circuit feedback, or how some of the output of a circuit can be put back into its own input (Holmes, 2008, p. 190). For Tudor, circuit feedback was a means of making audible the internal structure, character, and voice of the instrument (i.e. a means of externalising the internal and hidden).

He treated each collection of components as though it had a distinct personality and he was discovering its authentic nature. He accomplished this through feedback oscillation – the machines' spontaneous response to given conditions. For Tudor feedback was not noise, but rather the expression of the machine's persona (...). He'd set the knobs in such a way that when he increased the gain a very unpredictable thing would occur, that he'd react to. (Bischoff, in Manousakis, 2010, pp. 3–4)

This use of feedback can be related to the strong interest of the period in early cybernetic research (Eldridge, 2007). Similar sentiments are also echoed by Nicolas Collins (1991; 2002). For him, feedback has a dual role, representing the infinite

amplification of Cagean silence, and elucidating the connections between the internal and external:

[feedback] revealed links between electronics and acoustics, between circuitry and instruments, between structure and sound. (Collins, 2002, p. 6)

The notion of Tudor revealing the personality of his instruments is all the more pertinent for the fact that they are home-made and therefore inherently personal constructions. With commercially available (electronic) instruments institutionalised, too expensive, or of unsatisfactory design, Tudor learned to build his own circuits. He therefore differs from the likes of Hugh Le Caine and Moog in that he had no formal technical background, and from Cage and Schaeffer in that (although his work was often collaborative at a creative level) he generally did not call upon technicians or engineers to realise his ideas (Gray, 1999).<sup>13</sup>

Still searching for the unknown, he became almost fanatical about developing his own components. Typically he would change the resistance or capacitance values in a commercial design or, as he would say, "put an extra leg in it". (Gray, 1999)

Like the bedroom composers who followed in subsequent decades, Tudor turned this lack of expertise to his advantage, adopting (in place of understanding) a restlessly exploratory and open-ended approach that rarely saw the same instrumental configuration presented twice.

In the sixties, I learned from Tudor and Mumma that you didn't have to have an engineering degree to build transistorized music circuits. David

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<sup>13</sup> i.e. with the exception of the late works *Neural Synthesis* and *Neural Synthesis Plus*, their realisation did not much rely on technicians to realise his instruments.

Tudor's amazing music was based partly on circuits he didn't even understand. He liked the sounds they made, and that was enough.  
(Behrman, in Collins, 2009, xii)

Although the oeuvre of Tudor is considerably diverse, from modified traditional instruments (*Bandoneon!*) to analogue circuits, custom-fabricated chips (*Neural Synthesis Plus*), and multi-user installations (*Rainforest IV*), notions of the home-made and DIY are omnipresent (Driscoll and Regalsky, 2004; Tyranny, 2011). It would be difficult to mistake any of them for mass-produced or commercially-available equipment. This is responsible for a curious paradox, which, as Kuivila and Behrman (1998) assert, is central to understanding his work. On the one hand, the home-made (and therefore inherently personal and intimate) nature of the instruments is directly related to their potential for unique sounds and behaviours.

Electronic components and circuitry, observed as individuals and unique rather than as servo-mechanisms, more and more reveal their personalities, directly related to the particular musician involved with them. The deeper this process of observation, the more the components seem to require and suggest their own musical ideas, arriving at that point of discovery, always incredible, where music is revealed from "inside," rather than from "outside". (Tudor, in Adams, 1999)

On the other hand, their idiosyncrasies and (largely) undocumented complexities limit, through their impenetrability, the possibility of participation beyond the designer.<sup>14</sup> Faced with the possibility that the knowledge embedded in his instruments would pass with him, Tudor was eventually forced to confront this issue, although no satisfactory solution was found.

It wasn't until October, 1994 that he first asked for his music to be

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<sup>14</sup> i.e. limit the possibility of others playing the instruments.

performed without his active participation. Until that point, Tudor's music depended entirely on the direct involvement of his own musical character. Consciously releasing the notion of exclusive personal involvement, he accepted how his music might change with others performing it. His hope perhaps was that the performer would respect what he called "the view from inside..." (Adams, 1999)

This notion of the inside perspective is important, and will be revisited in Chapter 3 as the basis for an alternative understanding of performer-instrument intimacy.<sup>15</sup> The suggestion is that, given their personal investment in the instrument,<sup>16</sup> the designer-performer benefits from a privileged and perhaps definitive understanding that is beyond easy reach of other (outside) performers.

Beyond notions of the home-made and personal, it is also clear that the Tudor electronics offer a shift in emphasis away from physical (i.e. tangible) skills towards more overtly intangible (i.e. mental) ones such as listening (Manousakis, 2010). Instead of the tangible sense of cause and effect present in acoustic instruments (i.e. the palpable experience of the performance interface acting directly on the means of sound generation.), the Tudor circuits condense the interface and means of sound generation into a singular (but largely inscrutable) entity where tiny, barely perceptible actions can have hugely significant musical effect.

In contrast not only to acoustic instruments, but also many other electronic instruments such as the Michel Waisvisz cracklebox (STEIM, 2004), the Tudor circuits do not demand constant and direct interaction in order to produce sound. They are much more indirect, and may continue to produce sound long after the hand of the performer has let go. This hand does not exert close control but instead acts as a kind of modifying or steering influence (in the sense of Vertegaal, Ungvary and Kieslinger, 1996) as the instrument drifts along an uncertain and unstable path. Their nature is (inadvertently) captured by Alice Eldridge:

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<sup>15</sup> Similar notions are being explored elsewhere, for example by Randy Jones *et al.* (2009).

<sup>16</sup> We tend to value things we make more highly than things that are pre-made (Norton, Mochon and Ariely, 2011).

the system offers an attractive balance of autonomy and controllability. System behaviour arises from an internally controlled, open-ended configuration, but is parameterised by the degree of viscosity. Although it is "doing its own thing", we can induce it to operate within a given field. The characteristically different responses to different forms of input displayed also provide a form of global control. (Eldridge, 2007, p. 104)

Nevertheless, if the nature of control is fundamentally different to that offered by acoustic musical instruments (therefore terms such as influence, guiding, or steering may be more appropriate), this is quite different to being out of control (i.e. having no control at all). This is seen by John Adams (1999) to be of little interest to the performer:

Despite his inclination towards allowing the electronics to "speak", even Tudor knew that feedback was to be handled with care. When allowed to "take off", all of the desirable features of the feedback that Tudor was after would disappear: the variation and unpredictability was lost. (Adams, 1999)

While acoustic and Tudorian instruments both operate at the time scale of real-time performance, the suggestion is that, by reducing the demand for physical involvement, the Tudor case may consume less cognitive bandwidth. Thus, in the sense of Cook (2001; 2009), there may in some instances be spare capacity for listening and contemplation.

While much emphasis has been placed on Tudor, live electronics were also developed elsewhere. Notable figures include Robert Ashley, Behrman, Alvin Lucier, and Gordon Mumma in the US (collectively the Sonic Arts Union), AMM and Gentle Fire in the UK, Musica Elettronica Viva (MEV) in Italy, and the Stockhausen ensemble and associated groups such as the Gruppe Feedback in Germany (Manning,

2004, pp. 157; Holmes, 2008, pp. 274–281).

If acousmatic (i.e. tape-based, studio-produced) music, in its exclusion of the performer, represents a radical departure from musical tradition, the live electronics paradigm offers a link to traditional instrumental performance characteristics such as performance gesture, agility, improvisation, and audience engagement (Gluck, 2006). Yet at the same time, the live electronics paradigm also renders traditional definitions of musical instruments obsolete. Although some designer-performers simply developed new electronic instruments, Behrman explicitly posited (after being implied by Tudor) that electronic circuits could not only create and control sound, but also be, in themselves, a musical composition that is subsequently revealed or realised through exploratory performance. He writes:

because there is neither a score nor directions, any sound which results from any combination of the switch and light positioning remains part of the "piece". (Whatever you do with a surfboard in the surf remains a part of surfboarding.) (Behrman, in Cox and Warner, 2002, p. 213)

This blurring of the boundary between instrument and composition can be seen to demand an expanded understanding of musical instruments. This subject will be revisited later in this thesis, in the context of the digital musical instruments in the portfolio (see Chapters 4 and 5).

## **From Modular to MIDI Synthesisers**

If, by the end of the 1960s, the field of live electronics had produced numerous examples of agile, accessible,<sup>17</sup> and characterful performance systems, they were increasingly overshadowed by the development of the modular (i.e. programmable)

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<sup>17</sup> i.e. available to those without institutional budgets.



synthesiser. The first synthesiser able to be programmed by its operator was the Radio Corporation of America (RCA) Mark II Sound Synthesizer of 1956. Like the Telharmonium before it, the Mark II was an enormous, room-filling machine. Although its operation was entirely non-real-time, it offered, for perhaps the first time in an electronic instrument, complex control of sound (Dunn, 1992; Veil, 2000, ). For composers of the period, these new timbral possibilities held considerable appeal (see Barkin and Brody, 2001), prompting the development of more practical synthesiser instruments.



Fig. 5. The Buchla 100 modular synthesizer (Bennett 4 Senate, 2006).

By 1964, Moog had created the Moog modular system, one of the first monophonic modular synthesizers. This instrument introduced seminal notions of modularity and voltage control (Dunn, 1992; Hunt, 1999). In this model, functions are separated out

into distinct units (i.e. modules) that are subsequently connected by patch cables carrying audio and control signals.

first, that voltage control could be applied to an electrical musical instrument, and second, that the instrument could consist of discrete modules (oscillators, amplifiers, envelope generators, and, later on, filters) that could be wired together in a variety of ways and controlled by the output voltages of the devices themselves. (Pinch and Trocco, 2004, p. 28)

Approximately contemporaneously and on the opposite coast of the United States, Buchla worked to develop his 100 series synthesiser (see Fig. 5). This offered a distinctly different paradigm for modular synthesis (Bernstein, Goebel and Rockwell, 2008). While the Moog design assumed the keyboard as its primary means of control, the Buchla synthesiser, with input from composers such as Pauline Oliveros, Ramon Sender, and Morton Subotnick, was more open to alternative interfaces:

It would have been very easy for Don to provide preset voltage quantizers tuned to western scales. A large amount of extra design time and expense was spent including highly generalized scale sources. So trying to use a Buchla as a keyboard oriented western instrument is truly swimming upstream. (Richter, 2011)

Equally importantly, Moog merged audio and control signals together, making them essentially interchangeable, while Buchla considered it necessary to keep audio and control signals separate:<sup>18</sup>

I would say that philosophically the prime difference in our approaches was that I separated sound and structure and he didn't. Control voltages were interchangeable with audio. (Buchla, in Dunn, 1992, p. 22)

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<sup>18</sup> It is the Buchla model that informs the design of contemporary software such as Max and Pd.

By 1969 Moog had developed the more portable and affordable Minimoog, based around an organ-type keyboard and a less flexible architecture (Dunn, 1992; Veil, 2000). This became the standard model for many subsequent synthesisers. However, while other synthesiser manufacturers in the US (Serge), UK (ARP, EMS) and Japan (Korg, Roland, Yamaha) soon entered the market, incompatibilities between manufacturers persisted (Dunn, 1992; Hunt, 1999; Veil, 2000). This began to change with the ratification of the MIDI standard in 1983, and its subsequent widespread adoption in both professional digital synthesisers such as the Yamaha DX7 and TX81Z, and budget home keyboards by the likes of Casio (Roads, 1996, pp. 85-115; Hunt, 1999). Crucially, the assumed model during the development of MIDI was the keyboard synthesiser. Thus, while MIDI improved the accessibility of electronic music (Gehlhaar, 2002), it also solidified its relationship with the keyboard (Hunt, 1999; Miranda and Wanderley, 2006, pp. 2-3) and its scales (Igoudin, 1997), and emphasised the clean separation of the performance interface and means of sound generation (Paradiso and O'Modhrain, 2003).



Fig. 6. Roland GK-2A MIDI (TheMM, 2008).

A limited number of alternatives to the keyboard were developed, some by major manufacturers (e.g. Yamaha Corporation, 1999), but these were not widely adopted (Hunt, 1999). Guitar-to-MIDI converters (see Fig. 6), for example, were considered slow and unreliable (Paradiso, 1997; Hunt, 1999; White, 1999). The suggestion that MIDI is deficient or lacking resonates with the comment of Collins, that:

[MIDI is a] crudely quantized data format, optimized for triggering equal-tempered notes, and ill suited for complex, continuous changes in sound textures. (Collins, 2011, p. 1)

In other words, the homogenising effect of MIDI was such that the unpredictabilities,

inaccuracies, and other quirks of live electronics were ironed out and lost.<sup>19</sup> Thus, if electronic instruments went from the studios of well-funded institutions to the home in the space of only 20 to 30 years, this broadening of participation can be seen to have come at the expense of instrumental character and personality.

## **Interfaces for Computer Music**

When we have developed a methodology which allows us to determine the gesture which best suits the expression of a particular concept, then we will be able to build the user interfaces which today are only a dream. (Buxton, 1983, p. 36)

The next section will focus on developments in the area of computer music performance.<sup>20</sup> This was for some time a parallel strand to electronic music, before the technological convergence of the 1990s merged computer and synthesiser.

Imagine, first of all, you programmed everything on punchcards, then you submitted it and came back the next day, because the computer only ran one job at a time, and sometimes it would take hours and hours just to do anything at all. (Lansky, 1995)

Keen to surpass the limitations and laboriousness of initial musical interactions with computers, technologically-minded composers began to explore real-time methods of control.<sup>21</sup> One of the first solutions to be proposed was the GROOVE + CONDUCTOR system, developed by Max Mathews and colleagues at AT&T Bell

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19 Even the keyboard itself can be seen to have been cheapened, the responsive, weighted keys of the piano replaced by vastly inferior plastic similes.

20 The reader is therefore referred to Roads (1996), Charles Dodge and Thomas Jerse (1997), and Ge Wang (2008) for more general accounts of computer music and its developments.

21 A similar journey from off-line to real-time undertaken by the synthesiser.



Labs (Mathews and Moore, 1969; 1970; Manning, 2004, p. 377-379). The amount of musical control offered was limited, for it relegated the performer to the role of conductor (Hunt, 1999; Marshall, 2009).

As computers became increasingly capable and accessible, a small but significant number of composers and performers developed a wide variety of interfaces for computer music performance (Roads, 1996, pp. 108–334; Hunt, 1999; Bongers, 2006; Marshall, 2009). Iannis Xenakis, for example, developed the Unité Polygogique Informatique du CEMAMu (UPIC) system in conjunction with the Centre d'Etudes de Mathématique et Automatique Musicales (CEMAMu) in Paris. The UPIC is a digitising tablet primarily intended for graphical musical composition (Marino, Serra and Raczinski, 1993), but with some additional performance abilities (Hunt, 1999; Harley, 2004, p. 115). The user draws directly on the screen to produce sound. However, while this directness of interaction makes the UPIC simple to understand and use, it is a somewhat obvious and laborious approach to music creation. Nevertheless, its influence upon subsequent instruments is considerable. Perhaps the most notable examples are the Wacom instruments developed by Matthew Wright and David Wessel (1998) at the Center for New Music and Audio Technologies (CNMAT).

Other developments were somewhat more extreme, particularly with regard to their scale. At the intimate end of the spectrum, Waisvisz (1985) developed The Hands (see Fig. 7), a proto-wearable musical interface built around the gestural subtleties of the arm and hand. The D-shaped structures placed over the hands are festooned with sensors that enable gestures to be accurately measured. These include hand and arm movements, the distance between the hands, tilting of the wrists, and finger flex were then mapped to musical parameters (Hunt, 1999).



Fig. 7. The Hands, played by its inventor Michel Waisvisz (STEIM, 2011).

Perhaps the most interesting aspect of The Hands instrument is that Waisvisz spent many years performing with it in a fixed state rather than continually refining its abilities, becoming one of only a few new instrument virtuosi (Hunt, 1999; Jordà, 2005). Given its expressive capabilities and potential for long-term engagement and mastery, it may be useful to consider why The Hands model has not been more widely adopted.<sup>22</sup> To this end, its designer notes that:

Oh yes! The Hands is really difficult for other people to play. This is not just because the synthesizers are made to fit my own hands; it's also because the way one approaches the synthesizers through The Hands is heavily influenced by my timbral conceptions. (Waisvisz, in Krefeld, 1990, p. 30)

Around the same time, other figures worked to expand the musical interface towards the architectural scale. David Rokeby (1996) created the Very Nervous System (VNS) using a camera-like array of light sensors, while Gehlhaar (1991) created the SOUND=SPACE system (see Fig. 8). This utilises an L-shaped array ultrasonic rangefinders to register the movements of participants within a 10 by 10 metre space.

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<sup>22</sup> There are very few similar wearable musical interfaces.



Fig. 8. The SOUND=SPACE instrument c. 1985 (Gehlhaar, 2009).

These systems opened up the possibility of performing music to new (i.e. previously excluded) participants, from dancers to those with severe physical disabilities. While not quite mainstream, these kinds of spatial interfaces have found a niche (Hunt, 1999), and are quite common today in the fields of media arts, interactive media, and disability education (e.g. Swingler, 2011).

## Digital Musical Instruments

While the musical mainstream has yet to move much beyond the keyboard, academic interest in alternative interfaces for computer music has exponentially increased. The field became formalised in 2001 with the creation of the NIME conference series (Paradiso, 2002),<sup>23</sup> and this now represents the most important platform for new digital musical instruments. Indeed, it continues to be the only major conference to focus consistently and specifically on what Robert Rowe (1993, pp. 6–8) calls "instrument-player paradigms".

Nevertheless, to make sense of and classify the digital musical instruments presented at NIME is not a simple task. The Hornbostel-Sachs system (1961), for

<sup>23</sup> Originally an off-shoot of the 2001 ACM Conference on Human Factors in Computing Systems (CHI).



example, widely adopted for acoustic instruments, defines five top level instrument classes<sup>24</sup> based on their sound-producing material (Jordà, 2005). This is inherently unsuited to the digital instrument case, where the same computer can produce essentially any sound. An alternative is offered by David Birnbaums *et al.* (2005), who propose the following 7-D classification space for digital musical instruments:

- Role of Sound
- Required Expertise
- Music Control
- Degrees of Freedom (DoF)
- Feedback Modalities
- Inter-actors
- Distribution in Space

However, the forms of the approximately 350 new instruments presented at NIME since 2001 (see Marshall, 2009)<sup>25</sup> are so heterogeneous that even this extended classification cannot claim to be comprehensive. Moreover, the forms of these instruments are often so independent of musical output that the performance interface and means of sound production are designed separately (Jordà, 2005). To complicate matters further, many components have multiple possible applications. For example, an accelerometer can measure tilt and orientation in addition to acceleration (Miranda and Wanderley, 2006, p. 108–109; Marshall, 2009), while a 2-D wavetable can not only create a wide range of synthesised timbres, but also act as an audio looper. There thus exists the potential to slip between the gaps in almost any classification imposed. Moreover, the classification of digital musical instruments according to rigid criteria could be considered contradictory to the notions of coherent instrumental character and instrument environments proposed earlier in this thesis. Thus, while the next

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<sup>24</sup> Idiophones, membranophones, chordophones, aerophones, and the retrospectively added electrophones.

<sup>25</sup> Marshall (2009) identifies 250 instruments presented at NIME between 2001 and 2008. My own survey reveals another 100 instruments presented in 2009 and 2010.

section will delve inside digital musical instruments in order to consider their anatomy, it will do so only informally. The aim is to give the reader at least an indication of their diversity. It is important to remember that a digital musical instrument exists only when these elements are combined. However, while this typically involves a physical structure or body, unlike the acoustic instrument case, the bodies of digital instruments are not directly involved in sound production (Marshall, 2009). Thus, the materials used are able to be chosen for reasons other than acoustics. These may include, for example, their conceptual, emotional, visual, tactile (e.g. Kiefer, 2010; Marier, 2010), or industrial properties. As a result, the forms of digital musical instruments are far more diverse than those of traditional instruments. They include:

- augmented traditional instruments (Overholt, 2005; Schiesser and Traube, 2006; McPherson and Kim, 2010);
- hand-held objects (Singer, 2003; Quintas, 2010; Yamaguchi *et al.*, 2010; Schlessinger and Smith, 2009);
- mobile devices (Tanaka, 2004; Wang, 2009; Oh *et al.*, 2010);
- board games (Parson, 2009);
- surfaces (Taylor and Hook, 2010);
- tabletops (Patten, Recht and Ishii., 2002; Partridge, Irani and Fitzell, 2009);
- wearables (Marrin, 2000; Rodriguez and Rodriguez, 2005; Torpey and Jessop, 2009);
- larger-scale installations (Rodriguez and Rodriguez, 2005; Bongers, 2006).

Like their acoustic, electric and electronic predecessors, the majority of digital musical instruments are intended for a solo performer. However, the last decade has seen a spate of multi-user instruments (Ulyate and Biaciardi, 2002; Taylor *et al.*, 2010). This includes instruments that enable both local (i.e. the participants are in the same physical space) (e.g. Wang, 2008) and remote collaboration in the rhizomatic

space of the Internet (e.g. Martin, Forster and Cormick, 2010; Park *et al.*, 2010; Torre, O'Leary and Tuohy, 2010).

The following generic aspects of digital musical instrument anatomy will now be discussed in turn:

- sensors
- sound generation
- mapping
- sound diffusion and feedback

## **Sensors**

In a digital musical instrument context, sensors are devices that convert the actions of the performer (input) into an electrical output. They are thus of central importance to the performance interface, and the nature and quality of the performer-instrument interaction (Jordà, 2005). There are sensors to suit almost any conceivable application (Marshall, 2009). Indeed, so many different types are available that it would be foolish to try to list them all. However, it is important to distinguish between at least the following fundamental characteristics:

- tactile (contact) or non-contact actuation;
- discrete (i.e. on/off) or continuous output.

While some instruments include only discrete or only continuous sensors, the vast majority include a combination of the two. This is likely influenced by the acoustic domain, where instruments typically offer both continuous and discrete controls. With the basic parameters of interaction in place, Wanderley (Wanderley and Battier, 2000)

offers ten further considerations for sensor selection:

- sensitivity
- stability
- repeatability
- accuracy
- precision
- resolution
- span
- range
- linearity and selectivity of output
- sensitivity to ambient/environment conditions

It is important to note that few sensors communicate directly with the computer. They are instead usually connected by means of a microcontroller or dedicated sensor interface. It is therefore vital that the sensor interface is able to fully convey the range and responsiveness of the chosen sensors.

## **Sound Generation**

In most digital musical instruments, sound generation is no longer a physical process. It is instead dematerialised, realised entirely in code. This allows for enormous flexibility, for almost all historical synthesis techniques become available (see Roads, 1996; 2001), while at the same time new ones are continually developed (Marshall, 2009). However, while some of these find their way into digital musical instruments, with some notable exceptions (e.g. Couturier, 2002), few are designed (from the outset) to meet the unique demands of real-time instrumental performance. The

concern is that the demands of instrumental (i.e. real-time) and studio (i.e. non-real-time) use can be so different as to be fundamentally incompatible.

## Mapping

The connections between input and output are usually termed mapping (Winkler, 1995; Rovan *et al.*, 1997; Fels, Gadd and Mulder, 2002; Marshall, 2009; Schacher, 2010). In the acoustic domain these connections are largely predetermined by the choice of performance interface and sound generation mechanism, but in the digital domain these elements are not directly connected, and their relationship must be explicitly designed. While this can be essentially any desired (Jordà, 2005; Armstrong, 2006; Marshall, 2009), the right choice is vital, for input-output correspondence is a primary contributor to instrumental character, behaviour, and feel (Hinkley, 2002, p.161). While many subtle variations are possible, Wanderley and Nicola Orio (2002) identify four broad types of mapping:

- one-to-one: one input to one output
- one-to-many: one input to many outputs
- many-to-one: many inputs to one output
- many-to-many: many inputs to many outputs

It is notable that only the one-to-one type can reasonably be said to resemble the mappings found in acoustic instruments (Jordà, 2005; Armstrong, 2006; Marshall, 2009), while the other types represent substantial departures from the established and familiar. Indeed, Jordà (2005) asserts that even if the one to one case is considered desirable, the mappings present in acoustic instruments are often slightly non-linear (i.e. they contain expressive discontinuities) and may be difficult to replicate digitally.

The emphasis of the NIME conferences on the performance interface is such that other aspects are often considered modularly interchangeable (Jordà, 2004b; 2005). This increases the difficulty of mapping design exponentially, for the affordances and demands of performance interfaces and sound generation algorithms vary greatly from one to the next. For example, the control demands of subtractive synthesis are quite radically different from those of granular synthesis. Thus to develop any part of the instrument in isolation, in the hope that it can ultimately be mapped onto other elements, risks serious incompatibilities (Jordà, 2004b; 2005).

## **Feedback and Sound Diffusion**

Marshall (2009) notes that by far the most common forms of feedback provision in digital musical instruments are haptic and visual, and that other types of sensory modality are not used perhaps reflects their unsuitability for real-time performance. For example, temperature, taste, and smell feedback are used only very rarely (e.g. Miyashita and Nishimoto, 2004), and could be ruled out entirely on grounds of unresponsiveness and the difficulty of delivery and localisation respectively.

It is apparent that when additional haptic or vibrotactile feedback is incorporated into digital instruments, a typical aim is to recreate the performer-instrument experience found in acoustic instruments. As Marshall identifies (2009), perhaps the simplest method (and most immature of traditional instruments) is that proposed by Cook (2004), whereby a loudspeaker is implanted into the body or structure of the instrument so that some of its vibrations can be passed to the performer. Elsewhere, other digital musical instrument designs make use of small vibration motors (similar to those found in video game controllers) or tactors (a specialised kind of haptic actuator) (Oboe and De Poli, 2002; Howard, 2003; Steiner, 2004; Bennett *et al.*, 2007; Muller and Essl, 2009). Although there is not space to discuss them here, some more unusual methods have also been proposed, for example

by Alexander Müller *et al.* (2010) and Karl Yerkes, Greg Shear and Wright (2010). For a more detailed overview of haptic and vibrotactile technologies, the interested reader is referred to earlier work by the author and colleagues (Holland *et al.*, 2010; Bouwer, Dagleish and Holland, 2011a).

By contrast, when designers add visual feedback to digital instruments, there is often little or no attempt to recreate the experience of traditional musical instruments (although the likes of the ReacTable (Jordà, 2005) are clearly influenced by the modular synthesis paradigm). Instead, visual feedback is typically used to create what Nate Aldrich (2005) terms "artistic synaesthesia", whereby a collection of aesthetically driven stimuli reinforce a single idea or perception (i.e. one sensory modality is conceptually and perceptually fused with another). While computer displays and projection screens are the most common means of providing this visual feedback, there are again a variety of less-conventional methods (Marshall, 2009). These range from the double-sided LED matrix of the Yamaha Tenori-on (Nishibori and Iwai, 2006), to the water jets of the Hydraulophone (Mann, 2007). In both cases the visual feedback is well integrated into the performance interface, but interestingly, they not only provide the performer with feedback but also convey the (performer-instrument) interaction to the audience. Thus, the spectacle created can be considered integral to the performance; quite the opposite of frivolous pop spectacle (Cascone, 2000),<sup>26</sup> or what Godlovich (1998, p. 30) might call "entertainment".

Nevertheless, many digital instruments do not provide the performer with much feedback at all beyond their sound output (i.e. sound is the primary form of feedback) (Marshall, 2009; Nagashima, 2010). When the typical means of sound projection for digital instruments is a public address (PA) system, the sense that sound is produced by, and comes from, the instrument is yet further reduced. For Yolande Harris (2006), this effectively represents a turning "inside out" of the traditional paradigm of sound diffusion. Thus, some authors consider it desirable to return to a more localised acoustic model of sound diffusion. Again, the simplest

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<sup>26</sup> i.e. eye candy included to sate the desire for visual spectacle of audiences steeped in the customs of popular music.

model is perhaps the integrated loudspeaker design proposed by Cook (2004). A more sophisticated system is offered by the Princeton Laptop Orchestra (PlOrk), whereby each performer is provided with a standalone hemispherical loudspeaker array. These radiate sound evenly outwards in all directions, much like an acoustic object (Trueman, Bahn and Cook, 2000; Lock and Schiemer, 2006; Smallwood *et al.*, 2009), and there is a concerted sense of sound localisation for performer and audience alike.

## **Post-Digital Systems**

If the new interfaces and instruments scene is the most immediately relevant and important to this research, other lines of thought have been pursued in parallel. Subsequent to the release of the Apple PowerBook, for example, the late 1990s saw the spread of the laptop computer in performance (Monroe, 2003; Collins, 2006), closely allied to the emergence of what Cascone (2000) terms a "post-digital" aesthetic. For him, this trope relates to a diminishing enthusiasm for digital technologies as an end in themselves. Within this post-digital aesthetic, special prominence is given to software tools such as Max, Soundhack, and Metasynth (Grierson, 2005), and their potential for both sensory translation and for emphasising the detritus (i.e. accidents, errors, and other glitches) that lurks beneath the surface of the medium.





Fig. 9. Rosy Parlane, Performing @ Mono: Expansive Sonic Environments, Intersecting Audiospheres, Singularity of Sound (Parland, 2007).

In this realm, information can be extracted from almost any phenomenon or thing, then magnified and translated into other sensory modalities (Cascone, 2000). While performance aspects are not eradicated entirely (as is the case with acousmatic music), they are certainly (and for some audiences disconcertingly) downplayed (see Fig. 9).

A typical situation in laptop performance is that of a solitary performer behind his laptop (the performer more often than not is a male, although there are a number of notable exceptions including Kaffe Matthews and Ikue Mori) looking deeply into the screen. The musician's face is illuminated by the blue light emanating from the laptop's screen. His eyes raise in surprise, followed by a frown and a slight tut before he is again lost

in thought, his face blank. From the PA we hear numerous digital sounds, sweeping pitch bends blend into a vast array of static played at ear splitting volume. The slight finger movements of the performer cause the fragile pops and ticks to be displaced by a wall of sound seemingly made up of hundreds of layers of audio, which having freed themselves from the small black box and are now emanating from the walls and ceiling. (Stuart, 2003, p. 60)

In one common laptop performance practice, the laptop touchpad is used to start, stop, and manipulate multiple audio files (Cascone 2000; van Veen, 2002). Another notable kind of laptop performance practice is the live coding paradigm:<sup>27</sup>

Performance involves continuums of interaction, covering perhaps the scope of controls with respect to the parameter space of the artwork, or gestural content, particularly directness of expressive detail. Whilst the traditional haptic rate timing deviations of expressivity in instrumental music are not approximated in code, why repeat the past? No doubt the writing of code and expression of thought will develop its own nuances and customs. (Toplap, 2011)

The differences between these laptop performance paradigms and more traditional performance practices has led, at least in some quarters, to sustained criticism. These criticisms have tended to centre on audience experience, and the ambiguous relationship between gestural input and musical output in particular (Cascone, 2000; Stuart, 2003; Collins, 2006). One such argument is that the micro-gestures employed by the laptop do not communicate much of the expressive intention of the performer, and therefore the laptop can appear cold, clerical, and detached (Turner, 2003). Nevertheless, these issues are not unique or new to musical computers for they can be found elsewhere, for example in minimalist instrumental music by Morton Feldman:

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<sup>27</sup> Also known as on-the-fly programming.

he wanted to "get rid of the audience"; to write in a way that depended on a more intimate relation between performer and listener. The two needed time to get to know each other, he felt. (Fox, 1995)

A more extreme rejection of the computer and the digital is found in the alternative post-digital aesthetic offered by Richards (2006) (see Fig. 10).



Fig. 10. The Dirty Carter instrument by John Richards (Carter, 2010b).

In their openly hacked, hackable, and otherwise rudimentary constructions, these post-digital instruments directly recall the live electronic systems of the 1960s, and the last decade has seen renewed interest in the likes of Tudor, Behrman, Collins, and Reed Ghazala (Archer, 2004; Collins, 2009, x).

A development and interest in what could be described as "dirty

electronics" has taken root. These are electronic instruments and working methods that are directly opposed to those of a mass produced digital culture and may include some of the following characteristics: designer trash (deliberately made to look beaten-up or broken), ugly, cheap, heavy, hand-made, designed to be handled or to come in contact with the body, readymades, hacked, bent, feedback and kitsch. (Richards, 2006, p. 286)

While the sonic possibilities of these instruments are often inflexible (at least compared to those of a general-purpose computer), they have qualities such as portability, accessibility, and unique character on their side. As in the case of the Dirty Electronics Ensemble (see, for example, minimaljames, 2009), they are sometimes deployed en masse in an attempt to counter their individual (sonic) limitations.<sup>28</sup>

As stated in the introduction to this thesis, the aim of this research is to improve rather than abandon digital (i.e. mainly computer-based) musical instruments. The more moderate perspective offered by Garth Paine (2008, pp. 299–329) is seen to be appropriate here. He posits a shift in the role of the performer from someone who (after years of practice) has close or precise control over their instrument, to someone who more loosely steers their way through the labyrinthine pathways (i.e. structures) of a digital system:

Perhaps the notion of control is passé? Perhaps the laptop musician is not so much "in control" as they are navigating the potentials inherent in the work? If this is so, then performance gestures take on a very different function; their designation moves from an event based classification to encompass the notion of gesture as form and timbre as inter-relationships, influencing orchestration, focus, or structural evolution as the performance/musical work evolves. (Paine, 2008, pp. 299-329)

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28 i.e. lots of simple units can, taken collectively, produce music of considerable complexity.

This idea, already discussed in relation to the Tudor electronics, is of central and recurring importance to this research. It is revisited later in this chapter in relation to the situationist notion of the *dérive* (Debord, 1958).

## A Tudorian Framework

If the evolution of musical instruments since the introduction of electricity has been rapid and divergent, it is possible to identify a repeating cycle in which initial experimentation is followed by a retreat to the safe familiarity of the keyboard. By the 1930s, for example, the innovations of the theremin and Ondes Martenot had been left behind by a spate of more conventional keyboard instruments (Hunt, 1999). Similar trends can be seen throughout the 20th century. For instance, the characterful home-made electronics of Tudor and his contemporaries were soon marginalised by the success of the (keyboard-based) Moog synthesiser (Pinch and Trocco, 2004, pp. 131—135). Analogue synthesisers were then themselves succeeded in the early 1980s by digital synthesisers and the coarse segmentation of the MIDI protocol (based around the assumption of a keyboard-synthesiser paradigm [Hunt, 1999]). As a result of this focus on the keyboard, other interaction possibilities have been neglected, and the potential for other forms of musical expression restricted. For Collins, this limited focus led to a loss of musical spontaneity and surprise:

the shiny DX7 is no match for the unpredictability of a table of Tudor's home-made circuits. (Collins, 2011, p. 1)

More recently, the NIME conferences have showcased a large number of new instruments. However, notably few of these designs have been widely adopted (Jordà, 2005; Marshall, 2009; Paine and Drummond, 2009). Moreover, those designs that have found some favour, particularly in various sub-genres of techno music, have

tended to be simple, binary arrays of push buttons (e.g. Nishibori and Iwai, 2006). In both the keyboard and push button array cases there are issues with overly generic (and therefore ill-fitting) mappings. This research will now argue that the performer-instrument relationship, playability, and musicality of digital instruments may be improved by the adoption of a Tudor-inspired framework.<sup>29</sup> The role of the framework is twofold. First, to help understand digital musical instruments, and second, to aid in their design (i.e. its influence is bi-directional). Its aim is to provide a platform for a shift away from bland routine, safety, and musical conservatism, towards unpredictability, exploration, and offer a basis for the alternative notions of expressiveness, intimacy, and mastery that this shift requires. As stated in the introduction to this thesis, the framework consists of the following aspects:

- Emergence
- Nuance
- Skill and skilling
- Plasticity and meta-plasticity
- Expression, expressiveness, and spectacle
- The human turn
- (The nature of) experience
- Long-term engagement, learning, and mastery

These aspects are heavily interconnected, centred around notions of expression and expressiveness. While primarily influenced by the live electronics of Tudor, the framework draws on other eras and fields where these are considered useful or necessary, and is thus an extensively synthetic construction. The framework is also more personal than the first (survey) part of this chapter, with secondary sources filtered through and infused with my own (i.e. primary) experiences as a performer, designer-performer, and designer of instruments for others.

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<sup>29</sup> Note that this is different to the return to analogue suggested by Richards (2006).

## Emergence

Any audience, whether one person at one time, several persons at one time, or several persons at several times, will no doubt find a variety of meanings in the object, some dependent upon understanding the language in which it was intended to be an utterance, others perhaps not, some dependent upon understanding the intentions of its original author, others not, some of those no doubt not even foreseeable by the original author. (Guyer, 2010)

If it is obvious that, left to their own devices, end users sometimes find new and unexpected ways of using available technologies, the photographs of Marc Steinmetz (2011) make clear that it is also possible for even the most unlikely technologies to be re-imagined by the user if they have sufficient time and motivation. It must therefore be emphasised that while the subsequently presented framework hopes to further understanding of digital musical instruments and aid in their design, it is not intended to be complete or final, but to instead offer numerous points of departure for future work (not only by the author, but also interested others).

Indeed, this open-endedness could be considered an extension of the way in which musicians have historically sought to expand the scope of their music-making by finding imaginative and sometimes highly personal possibilities in their instruments (Wilmoth, 2011). For example, the first percussion instruments are thought to have been stones, rocks, sticks, and bones (Morley, 2003). These differed from other (i.e. non-musical) stones, rocks, sticks, and bones strewn across the prehistoric landscape primarily (and perhaps only) by way of the ingenuity of their users.<sup>30</sup>

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30 This is one reason the interpretation of these objects remains a difficult task for archaeologists (Morley, 2003).

The phonograph (turntable) offers another historical example. Invented in the 19th century, the 20th century saw the turntable transformed by its users from a device for the playback of recorded sound into a performance instrument of considerable subtlety (Toop, 1984, p. 63; White, 1996; Hunt, 1999). In this case, the technology not only had previously untapped potential, but possibilities that were perhaps inconceivable to the original designer. While they may not all be useful or desirable, at their best, these newfound possibilities can considerably expand the expressive capabilities of an instrument.

Even the piano; an apparently sedate and settled instrument design, has been the subject of much performance innovation over the same period. The list of "extended techniques" developed for the instrument is much too vast to cover comprehensively here, but includes:

- (temporary) preparations of the strings;
- strumming the strings of the instrument inside the lid;
- singing and shouting into the soundbox of the instrument (Burtner, 2005).

It may even be that the development of these innovations has been encouraged by the relative immutability of the basic piano design; in other words that it offers a solid, well-understood platform that acts as a fertile ground for experimentation. Taking this line of thought further, it is possible to consider musical instruments in terms of what Simon Waters (2007) calls "emergence", or how complex behaviours can result from simple initial conditions in ways that may be counter-intuitive or surprising (Corning, 2002).

To reframe this, what Barrett is identifying is ultimately the notion of emergence – of systems or devices which, in Cariani's terms, outperform the designer's specifications. Situations in which the behaviours which are afforded cannot be accounted for solely by the designed outcome. (Waters,



Over time, some of these newfound possibilities and enticed behaviours are lost, but others are remembered and accumulated in the cultural construction of the instrument. In other words a musical instrument is not only a physical form, but also a cultural construction, complete with its own conventions and expectations. These ephemeral aspects may change over time, even if the instrument design does not. They can also just as easily contract as expand. After an initial period of interest, the Ondes Martenot (see Hunt, 1999), for example, fell sharply out of favour. For the second half of the 20th century, few people learned to play the instrument. Fewer still attempted to expand its performance possibilities. In the late 1990s, the instrument was revisited by the Radiohead guitarist and film composer Johnny Greenwood. His extensive use of the instrument on numerous recordings, television appearances, and live performances has, to a limited extent, returned the instrument to the public consciousness. A similar trajectory (rise, fall, modest revival) can also be seen to apply to the theremin, and, to a lesser extent, the electric guitar.<sup>31</sup>

Especially when the performer is involved in the design or modification of the instrument (this is not often the case with acoustic instruments), ephemeral performance possibilities (i.e. extended techniques) may start to be accumulated, and more permanently affect and shape its form. This cyclical process of build, play (as a way of testing), modify, play is typical of many electronic music practices subsequent to Tudor. Indeed, as the Bliptronome (Kirn, 2010) demonstrates, with information widely available on the online, digital musical instruments appear to be particularly receptive to being plied into new shapes. Even the typically functional, non-precious appearance of digital musical instruments (Richards, 2006) can be seen to encourage modification in a way that the pristinely smooth finish of more traditional (i.e. acoustic and electric) instruments does not. With the growth of communities based around selected instruments (the Monome, for example [Dunne, 2007]), it is even

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31 The cultural capital of the latter has ebbed and flowed since the sixties, often in counterpoint to that of the synthesiser, and later the turntable.

possible to conceive of instruments that are subject to quasi-Darwinian evolution as, over time, the community iterates and refines a common design. This principle has already been established elsewhere (Kirn, 2010).

## **Nuance**

If any framework for digital musical instruments must expect the unexpected, it is apparent that current approaches are also rather binary. As Jordà (2005) and others (Weinberg, 2002; Miranda and Wanderley, 2006, p. 90) make clear, previous computer music interfaces and instruments have tended to occupy one of two extremes. On the one hand, there are simple, accessible instruments intended to be played by novices (Machover, 2002; Robson, 2002). Often however, their quest for broad appeal can result in limited, short-lived sound toys that do not support long-term engagement (i.e. attempts at universality can be harmful). On the other hand, there are musically sophisticated instruments intended for expert musicians, or sometimes one expert in particular (Paradiso, 2011). These instruments can be so complex as to be impenetrable outside of a small circle of users (and perhaps just one). Nevertheless, if both extremes are flawed, and finding a desirable middle ground (i.e. instruments that appeal to both novices and experts) poses considerable challenges (Jordà 2005), it is possible to identify between cases that demand more nuanced understanding than novice/expert and simple/complex distinctions would admit. HEAD=SPACE (Gehlhaar, 2006), created for Clarence Adoo, is an example of such an instrument. Adoo is an expert trumpeter paralysed from the neck down in a car accident. While his physical abilities are much reduced, his musicianship skills, honed over decades, remain essentially unchanged. Thus, while circumstances dictated that any new instrument must, by the standards of traditional instruments, be extremely accessible, Gehlhaar (2006) considered it equally important to develop a musical instrument with real depth and potential for long-term engagement. While

such instruments remain atypical, a more nuanced understanding of digital musical instruments may be increasingly necessary as the field continues to develop. By making the field more porous, it may even create opportunities for growth, opening up new design spaces for digital musical instruments to explore. At the very least, it is a useful reminder that, when discussing concepts such as accessibility and mastery, it is necessary to proceed with an acceptance that what applies to one case may not always apply elsewhere (i.e. that musical instruments may not be entirely generalisable).

## **Skill and Skilling**

The HEAD=SPACE example also touches upon wider issues of skills and skilling in relation to digital musical instruments. It is clear that some attempt to leverage not only hard-won existing instrumental skills, but also accumulated intuition as to how objects and materials will feel and sound when physically manipulated (i.e. their designers try to make use of years of previous practice and skill development, and offer a reassuring sense of familiarity). These typically take one of two forms:

- traditional instruments augmented with sensors and actuation devices (Freed *et al.*, 2006);
- instrument-like (Marshall, 2009) systems that try to capture or recreate the feel (i.e. passive haptic sensation) of familiar performance interfaces such as the flute, trumpet, or violin, but usually do not imitate them entirely.

At the opposite end of the spectrum some performance systems are so unfamiliar as to render traditional instrumental skills fundamentally obsolete, demanding instead that the performer develop entirely new and different skills. From personal experience, I can attest that years of playing the trumpet and guitar does not much

develop the abilities needed to (for example) live code. The two domains are so different as to perhaps be incompatible, and there certainly appears to be little obvious correlation between the two. Again however, digital musical instruments can fall between these extremes. For example, the Double Slide controller (Henriques, 2009) is played in a manner that recalls the trombone, but, while some skills may be transferable between the two, they are far from identical; the newer instrument features several more degree of freedom, and, without any kind of comparative study, it is unclear as to how similar (and, correspondingly, transferable) their demands really are.

This is not to imply that these issues have originated with, and are unique to, digital instruments, for kindred issues can be identified in the Tudor electronics developed half a century ago. For example, while Tudor is widely recognised as a virtuoso pianist, the extent to which these physical skills remained relevant after the transition to electronic music designer-composer-performer is unclear. It may be that only more intangible skills, for example those related to musicianship and interpretation (Tudor and Schonfeld, 2004) (e.g. related to interpretation, improvisation, and listening), made the jump from the acoustic to the electronic domain. Moreover, if the Tudor electronics may be seen to demand different (if not fewer) skills to traditional instruments, thereby suggesting a broadening of participation (or at least the possibility of this), notably few novices set out to play live electronics.

## **Plasticity and Meta-plasticity**

If the differences between acoustic instruments are considerable (Kartomi, 1990; Jordà, 2005), the differences between digital and acoustic instruments are even more pronounced (Magnusson and Mendieta, 2007). Indeed, as the introduction to this thesis suggested, in some ways the two are so different as to appear only tangentially

related. Yet, the most obvious difference; that digital instruments can produce many more sounds simultaneously (Cottle, 2005; Jordà, 2005), is not necessarily the most radical or important departure. Instead of scale, it is perhaps a question of plasticity. While the parameters of acoustic instruments are, unless physical (i.e. permanent) changes are made to their designs, essentially fixed, the parameters of digital instruments are, through a variety of means, able continuously to evolve (Jordà, 2005; Miranda and Wanderley, 2006, p. 240), changing, in real-time, both their mappings (Arfib, 2005; Brandtsegg, Saue and Johansen, 2011); and therefore their behaviours and feel, and their sound. Jordà (2005) relates this to the ability to change shape, for example from narrow and deep like a trumpet to thin and wide like a piano, and out into forms so wide as to be impossible in the acoustic domain. Similarly, in terms of the models offered by Wanderley and Orio (2002), the mappings of digital musical instruments are able to change between one-to-one, one-to-many, many-to-one, and many-to-many configurations of input to output.

Classical music, like classical architecture, like many other classical forms, specifies an entity in advance and then builds it. Generative music doesn't do that, it specifies a set of rules and then lets them make the thing. In the words of Kevin Kelly's [1994] great book, generative music is out of control, classical music is under control. (Eno, 1996)

The immediate antecedents of this plasticity are found in generative music (Eno, 1996; Winkler, 1998; Essl, 2002), software presets (Jordà, 2005), modular synthesiser patching, and the real-time restructuring of modules in Pulsers (Tudor, 1984).<sup>32</sup> It also more broadly relates to the notion of neuroplasticity.<sup>33</sup> This concerns the capacity of networks in the brain to change their connections in response to new stimuli, thereby altering their behaviour (Rugnetta, 2011). While many digital musical instruments consider only the present (or most recent) action of the

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<sup>32</sup> However, as opposed to the discrete jumps of plugging/unplugging patch cables, the evolution of digital musical instruments is able to be smoothly continuous.

<sup>33</sup> Indeed, it is from here the title of this section is derived.

performer when generating their output, a few implement a memory so that previous (i.e. accumulated) stimuli can influence the current response. These cases are more similar to the notion of meta-plasticity developed by Wickliffe Abraham and Mark Bear (1996), or how previous activity determines current synaptic plasticity.

Given the close connection between how an instrument behaves, the sounds it produces, and its (perceived) character and (culturally constructed) identity, it is unsurprising that digital musical instruments do not currently have much of a distinct identity (at least beyond rather one-dimensional notions of coldness). Indeed, their identity can not only change, moment-to-moment, from any to any other, or any point in between (i.e. a hybrid). It is therefore possible to consider digital musical instruments as shape shifters par excellence.

Nevertheless, for a number of reasons, it has usually been considered desirable for musical instruments to possess a single, distinct character. This, for example:

- helps to reinforce intuition as to how the instrument should behave and sound;
- provides useful compositional limitations;
- helps to suggest complementary and contrasting instrumentation.

The latter may account for how certain instruments become archetypal, while similar (and therefore less distinct) instruments are subsumed or fall out of favour (Marshall, 2009). The absence of a distinct digital musical instrument identity may therefore be problematic, for the criticisms aimed at MIDI instruments, namely that their versatility leads to a homogenised blandness where previously there was the potential for nuanced expression (Lanier, 2010, p. 8–18),<sup>34</sup> may continue to apply.

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<sup>34</sup> Their fate could be contrasted with that of earlier analogue synthesisers. Despite being somewhat less flexible, their distinctive characters have come to be highly valued, providing the foundation for entire musical styles (cosmiche music, acid house, techno, dubstep, etc.).

## Expression, Expressiveness, and Spectacle

Given this mention of expression, it would appear a pertinent moment to consider expression and expressiveness in the context of digital instruments.

Expressiveness in music, as in all the arts, can have different meanings. Expressiveness is the capacity to convey an emotion, a sentiment, a message, and many other things. It can take place at various levels, from the macroscopic to the microscopic scale. In the case of musical performance, expressiveness can be associated with physical gestures, choreographic aspects or the sounds resulting from physical gestures. The design of a digital instrument must take its expressive possibilities into account. (Arfib, 2005, p. 125)

The difficulties involved are substantial, for expression and expressiveness are two of the most slippery and elusive concepts imaginable. As Justin London (2000) makes clear, there are numerous possible interpretations and meanings. At one end of the spectrum there is the decidedly pragmatic and practical approach adopted by Antonio Camurri *et al.* (2001). They focus solely on mechanical aspects of expressive gesture, with the aim of producing quantifiable results. Christopher Dobrian and Daniel Koppelman (2006), by contrast, emphasise less tangible, hedonic qualities such as the vivid depiction of mood and sentiment. They suggest that in order for something to be expressive, it must possess the ability effectively to convey meaning and feeling respectively. The situation is eloquently expressed by Daniel Arfib (2005), in that it is not usually necessary for the performance gestures themselves to be expressive, but for these gestures to create expressive sounds. Moreover, some electronic and digital instruments have little or no gestural aspect (the live electronics of Tudor are a good example of this), and it is far too simplistic to say that these instruments are inherently inexpressive. Thus, to consider expression in (easily measurable) visual

terms alone can be deceptive. While the more subjective understanding offered by Dobrian and Koppelman (2006) may make the design of expressive digital instruments more difficult (Fels, Gadd and Mulder, 2002) (and may even generate additional complexity), it can only be considered more appropriate in the context of this research.

However, if it can be deduced that expression is rooted in sound and, more specifically, how sound is produced (i.e. the performer-instrument relationship), it is difficult to assess expressiveness through auditory phenomena alone. Especially where the reference points provided by a score are absent, meaning is often unclear and thus the visual continues to be of importance.

Laptop music for example, is related to the acousmatic paradigm, but reintroduces the performer. However, despite their presence, the laptop performance paradigm has often been labelled inexpressive (Stuart, 2003). Digging deeper into these criticisms, however, it is apparent that the issue is not so much that electronic and digital instrument performance offers less expression, for performers are still realising their ideas, perhaps even more directly than before (Cascone, 2000). It is perhaps instead that, in its adoption of impenetrable micro-gestures, the laptop performance paradigm does not adequately convey its message to the audience. As Justin Donaldson describes:

Musical performances using laptops as a sole performance interface can suffer from a lack of audience engagement. Due to the limitations of gesture variety, magnitude, and overall lack of expressive performer behaviors, the audience members are often unable to associate the acoustical sounds of the music with the performer. In the absence of a compelling visual point of reference, audience members accustomed to the standard conventions of contemporary musical performance can have negative responses or a lack of interest in the performance, regardless of their interest in the music. These negative responses adversely affect the



engagement level of the spectator, and detract from the performance experience as a whole, limiting the effectiveness and potential of laptop music as performance art. (Donaldson, 2006, p. 712)

This leads to a variety of misunderstandings, conflicts of expectation, and tales of performers (apparently) completing their tax returns while on stage.

people seem to always be working, even when we're playing, because the tools of work have become the tools of leisure, thereby making leisure virtually indiscernible from work (Alexander, 2008)

It is possible to conclude that while the visual gesture may not be the root of expression, it is a prerequisite for its transmission to an audience. In other words, the visual gesture is responsible for amplifying the performer-instrument message to the extent that it may be clearly received and understood by the audience.

Nevertheless, in the digital instrument case, although (such is the range of sensors available) almost any gesture imaginable can be used, these are not all equally desirable. No longer directly involved in sound generation (they are always mediated and interpreted), it is all too easy for performance gestures to appear exaggerated and unnecessary. Even those gestures that were perfectly reasonable in the acoustic domain can appear hopelessly cartoonish in the digital domain: initial amusements aside, air guitar cannot be considered an aspirational model for digital musical instruments. Thus, a distinction can be made between primary/necessary and secondary/supporting/incidental gestures. Elena Muñoz (2007), for example, argues that if gestures are to feature in performance, they should not only provide a visual accompaniment to the auditory (i.e. be complementary to the performance), but also intrinsic to and necessary for the generation of sound. When a gesture integrates or fuses both roles, he suggests, it assumes a kind of added value:

When both co-exist, and are perceived as one, the experience of

performance becomes free and, paradoxically, the fusion between player and instrument reveals the symptoms, not their realities, of music's existence; those that Claude Debussy found "among notes". To see is to perceive. Seeing performers' gestures as they play strongly influences the particular kind of data registration that accompanies the listening in the total perception of the performance. (Muñoz, 2007, p. 57)

I employ the term "added value" intentionally, so as to recall the use of the term by Chion (1994, p. 5) in the context of film. This relates to the way in which a sound can enrich an image (i.e. quite the opposite of the digital musical instrument performance case), creating the impression that meaning comes from the image itself. Considering similar issues from a different perspective, Jordà (2004a; 2005) repurposes the notion of efficiency, often used in the context of engineering and HCI, for the digital instrument context. He proposes the following logical development:

1. Efficiency = Output/Input (in an engineering context)
2. HumanEfficiency = Effectiveness/Effort (in an HCI context [Macleod, Bowden and Bevan, 1997])
3. MusicalInstrumentEfficiency =  
MusicalOutputComplexity/MusicalInputComplexity (in a digital musical instrument context)

This notion of musical instrument efficiency concerns an instrument providing the widest range of musical possibilities<sup>35</sup> for a given mental and physical input. Combining these ideas of efficiency (Jordà, 2004a; 2005) and gesture (Muñoz, 2007), it can be suggested that only when gesture fuses sound generation and visual accompaniment can it be considered efficient.

The involvement connected with a piano differs strongly from that of a

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<sup>35</sup> He relates this to musical range (Blaine and Fels, 2003) and expressive range (Settel and Lippe, 2003).

hearth or a CD-player. A piano asks for interaction with its 'machinery', whereas a hearth evokes interaction with its environment: it demands that wood be chopped, and that it is cleaned regularly. A CD-player, in its turn, enables people to be involved with the music it reproduces. (Verbeek, 2002, p. 84)

Nevertheless, if a playback-only CD player (Jordà, 2005) or one-button Max patch is compared to a piano, it is clear that, while some efficiency is necessary if the instrument in question is not to appear Rube Goldbergian, too much efficiency can compromise expressiveness. Thus, the most efficient musical instrument may not be the best (Jordà, 2004a; 2005). To negate the effects of poor (i.e. limited, restricted, or faked) performer-instrument interaction when considering musical instrument efficiency, Jordà (2004a; 2005) adds the additional criterion of "performer freedom." This encompasses the freedom of movement available to the performer (i.e. DoF) as well as their freedom of choice. This leads him to the following updated formula:

$$\text{MusicalInstrumentEfficiency} = \frac{\text{MusicOutputComplexity} * \text{PerformerFreedom}}{\text{ControlInputComplexity}}$$

The possibility that instruments can be too efficient (Jordà, 2005), as well as the topic of performance gesture more generally, is closely related to notions of effort and effortful performance. To return to the example of laptop music, while *musique concrète* is more emphatic in its elimination of human toil from the production of musical experience (Croft, 2007),<sup>36</sup> laptop music reinstates the performer, but does so in a way which can appear, while not effortless per se (in the manner of a BCI, for example), at least inconsequential. This is especially the case for those audiences unfamiliar with its practices and codes (Cascone, 2000) (i.e. the majority of the population). While the clerical nature of the laptop performance paradigm has been vehemently defended by its practitioners (Cascone, 2000; Stuart, 2003; Collins,

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36 Although sound diffusion may maintain a human performance element.

2006), it is subject to criticism on the grounds identified by Joel Ryan (1992). This relates to the fact that effort has traditionally been so closely tied to the perception of expression that it is often considered a prerequisite for expressive performance. As Alistair Riddell suggests:

in a more refined state [effort] becomes a kind of externalised emotion mapped to the sound. (Riddell, 2009, p. 33)

If, up until now, effort may be essentially indistinguishable from gesture (and they are very closely related), it is possible to make a distinction between the two. Effort, for example, implies a physical resistance that must be overcome in order to produce sound. It also implies a sense of performer-instrument struggle. Such resistances are not innate to digital instruments as they were in the acoustic domain. If present, they are usually an addition to the instrument rather than the direct result of the performance interface/sound generation combination (Marshall, 2009). This may explain why although a wide variety of gestures are present in digital instruments, the performer-instrument relationship can often be underwhelming. Without entering into debates regarding authenticity (there is little to be gained from this), there is often a lack of what Cascone (2002) (after Benjamin, 1998), calls "aura". In this context, aura relates to there being something special about observing the performer dialogically engage with the means of sound generation in traditional instruments (Marshall, 2009).<sup>37</sup>

Nevertheless, it is necessary to resist oversimplification. There are also, simultaneously, issues of uncertainty and a lack of trust in the performer-instrument relationship stemming from the tendency of digital instruments towards unpredictable responses.<sup>38</sup> As a result of their plasticity, the same gesture may have an entirely

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37 That the projection of the laptop performer's desktop; while apparently exceedingly transparent and revealing, seems to be considered a poor substitute for the presence of more traditional (and palpable) performer-instrument engagement may relate to physical effort being much more widely understood. Not everyone can follow code, even projected onto a large screen fewer still can read it more closely: its meanings are much more obfuscated than physical gesture.

38 Remember that, after Collins (2003), this unpredictability may be desirable, and by design.

different effect each time it is deployed. To give a typical (albeit mundane) example, a left mouse click may variously instigate a sound of enormous complexity, radically alter the structure of the (software side of the) instrument, or have no effect at all (Jordà, 2005). Thus, if effort is primarily responsible for establishing causality of sound, this can not only be loose (i.e. through the use of one-to-many mappings and generative musical systems), but also variable from one moment to the next. The confusion that arises can perhaps be summarised in the following juxtaposition:

Any sufficiently advanced technology is indistinguishable from magic.  
(Clarke, 1962, p. 14)

Magic is just a way of saying "I don't know." (Pratchett, 2008, p. 157)

Despite these complications, performers, increasingly attuned to issues of effortful and expressive performance are re-embracing instrumental (in the broadest sense) paradigms:

For some performers, there is something appealing about physical exertion in creating a sound or playing an instrument. Micro-gestures suitable for many digital interfaces only allow for a fraction of the gesture range of the human body. (Richards, 2006, p. 286)

At the same time, it is clear that both what it means to play an instrument (i.e. the meaning of this instrumental turn) and the nature of the instrumental experience (i.e. what it is like to play an instrument) have been transformed by the transition from acoustic to digital. Beginning with the meaning and implications of the human turn, these issues will now be considered in turn.

## The Human Turn

Given the implied presence of a performer, a return to the instrument is also, perhaps unavoidably, a return to the human. After all, musical instruments are essentially specialised tools; in other words implements made by humans to carry out a particular function, in this case the (semi-)controllable production of sound.<sup>39</sup> The home-made (i.e. handmade) electronic instruments of Norbert Möslang (2004), Richards (2006), and Chris Carter (2010a) are, in their abundance of character and personality, a world away from the (apparently) cold sterility<sup>40</sup> of the computer. But even the recent spate of robotic instruments (Gimenes, Miranda and Johnson, 2007; Kapur, Singer and Tzanetakis, 2007; Weinberg and Driscoll, 2007; Weinberg *et al.*, 2009; Pan, Kim and Suzuki, 2010; Solis *et al.*, 2010), with their evident absence of emotionality, warmth, and agency (Eyssel, Bergmann and Kopp, 2011), can be seen to spur a longing for the human.

Some people even ask "How could computers make mistakes?" as though, somehow, ability to err itself might be some precious gift. There's nothing wrong with seeking for some precious quality, but only some form of quiet desperation would lead one to seek for it in error and mistake. (Minsky, 1982, p. 6)

Moreover, the instrumental turn is, in contradiction to the above quote from Marvin Minsky, also a tacit imprimatur of human qualities in musical performance. These include purposeful deviations from a musical text that are typically considered expressive (see Chapter 1), but also performer hesitation, inaccuracy, and other (often unintended) outcomes of effortful performer-instrument engagement and struggle. This embrace of accident and (human) error has significant musical tradition, from

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<sup>39</sup> This fits with the definition of music as organised sound outlined in Chapter 1.

<sup>40</sup> Note that a computer was originally a job role, whereby a person would undertake repetitive calculations.

Cage<sup>41</sup> to the Portsmouth Sinfonia.

In *26' 1.1499" for a String Player* (1954), Cage makes demands that even a virtuoso performer such as Charlotte Moorman (who performed the piece at its premiere) cannot hope to meet. At the same time, it is crucial that the performer tries to realise the score as accurately as possible, despite the futility of this aim. The subsequent performer-instrument struggle has two primary effects. On the one hand, it creates a sense of dramatic tension; the sense that the performer is on the edge of control is palpable. On the other hand, in a parallel with generative musical systems, the resulting mistakes create an unpredictable experience; the outcomes of the piece are different each time it is performed (Peters, 2008).

Influenced by Cage, the embrace of human error underpins the ethos of the Portsmouth Sinfonia. Formed in 1970 at the Portsmouth School of Art (Nyman, 1999, p. 162; Telegraph Group, 2004), the founder of the group, the composer Gavin Bryars, maintained a distinctively open and inclusive admission policy. Anyone was encouraged to join, regardless of musical ability or experience. Thus, the group featured both novices and experienced musicians playing unfamiliar instruments. There was just enough proficiency for the pieces to be recognisable, although they were often warped far beyond their canonical shapes (h2g2, 2001).

Technical shortcomings were here turned to positive advantage as an agent of transformation, and processes of deviation and decontrol long regarded as legitimate in the visual arts (in the works of Pollock, de Kooning, Johns and Rauschenberg, for example) were transposed into a musical context with unexpected and often hilarious results. (Parsons, 2001, p. 9)

The two cases are in some ways opposite; one demands virtuosity, the other celebrates amateurishness. Nevertheless, despite their use of traditional instruments, both demand an understanding of expression that transcends simple, measurable accuracy; there are certain to be unintended departures from any text. They also

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<sup>41</sup> Indeed, it may be considered a post-Cagean tradition.

require a post-Cagean acceptance that it may not be possible to know or even predict the most interesting outcomes in advance (and therefore that errors can be desirable).

The electronic instruments of Tudor, meanwhile, project a subtly different dynamic. While the fixed<sup>42</sup> possibilities of acoustic instruments provide definite points of reference, even in the absence of a score,<sup>43</sup> these reference points are absent from the unpredictable Tudor electronics. It is not therefore appropriate to consider them in terms of error, for to err requires there to be a consistent line representing the normal or expected in order for deviations to be recognisable. The same can be said of digital instruments; their potential for real-time plasticity is not conducive to the provision of fixed reference points. Thus, instead of the focus being on the musical outcomes of the performer-instrument struggle, it is the performer-instrument relationship itself that is projected to the audience. The basis for this relationship also has more potential for variation, from the synergetic to entirely non-dialogical.

The nature of this relationship will now be explored in more detail. This relates to the performance psychology of digital musical instruments. Particular attention is paid to the notion of control.

## **(The Nature of) Experience**

the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it. (Csikszentmihalyi, 1991, p. 4)

The experience of playing a musical instrument has sometimes been considered in terms of "flow" (O'Neil, 1999; Custodero, 2008). The concept of flow was developed

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<sup>42</sup> At least moment-by-moment, although, as asserted earlier in this chapter, design changes are possible over longer periods of time.

<sup>43</sup> Their long histories mean that it is intuitively understood how they are played and sound.



by Mihaly Csikszentmihalyi in the 1970s. While conducting interviews with a large and diverse population, he found that when the activity performed provided a close match between the skills of the participant and the performance demands, a common subjective experience would occur. Under these optimal conditions, participants experienced increased interest and pleasure; some even reported reaching an ecstatic state that he called flow (Csikszentmihalyi, 1977; 1991). Nevertheless, if the flow concept may be appropriate in the case of acoustic instruments, it is less applicable to instrumental engagements in the digital domain. Whereas flow implies an unbroken, smoothly directed, and linear experience, the experience of digital musical instruments is not only more uncertain, but often, moment-by-moment, discontinuous. There are peaks and troughs, often in quick succession, and even the most experienced performer can be unceremoniously thrown off course by the unexpected behaviours of the instrument. If there is any consistent sensation across digital musical instruments, it is perhaps the sense of exploration described by Paine:

Perhaps the notion of control is passé? Perhaps the laptop musician is not so much "in control" as they are navigating the potentials inherent in the work? If this is so, then performance gestures take on a very different function; their designation moves from an event based classification to encompass the notion of gesture as form and timbre as inter-relationships, influencing orchestration, focus, or structural evolution as the performance/musical work evolves. (Paine, 2008, pp. 301)

Taking this further, it may be that a willingness to wander and explore is a prerequisite for playing, enjoying, and making the most of the potentials of digital instruments. Thus, instead of flow, the Situationist notion of the *dérive* (meaning drifting or to drift) may be more appropriate.

One of the basic situationist practices is the *dérive*, a technique of rapid

passage through varied ambiances. *Dérives* involve playful-constructive behavior and awareness of psychogeographical effects, and are thus quite different from the classic notions of journey or stroll. (Debord, 1958)

In a *dérive* one or more persons during a certain period drop their relations, their work and leisure activities, and all their other usual motives for movement and action, and let themselves be drawn by the attractions of the terrain and the encounters they find there. (Debord, 1958)

For Owen Hatherley (2009, p.11), the *dérive* is intrinsically connected to the experience of architectural modernism, and maze-like suburban housing estates in particular. The suggestion is that, given its resonance with both the comments of Paine and the labyrinthine interconnectedness of the Tudor electronics, the concept may be transposable to the digital instrument domain. In this new context, the *dérive* recalls how, in the instruments of Tudor, the performance delineates the compositional ideas embedded in the instrument (see Chapter 2), and connects the design of Tudorian digital musical instruments to concepts of psychogeography and psychogeographical contours. These are respectively defined by Guy Debord as:

the study of the precise laws and specific effects of the geographical environment, consciously organized or not, on the emotions and behavior of individuals. (Debord, 1955)

constant currents, fixed points and vortexes that strongly discourage entry into or exit from certain zones. (Debord, 1958)

If these are clearly similar to the concept of perceived affordances developed by Donald Norman (1988, p. 9; 1999),<sup>44</sup> its HCI associations are not desirable in the context of this research. Indeed, as Norman himself acknowledges, the term is often misused:

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<sup>44</sup> This is itself appropriated from the concept of affordances developed by James Gibson (1979).

I was quietly lurking in the background of a CHI-Web discussion, when I lost all reason: I just couldn't take it anymore. "I put an affordance there", a participant would say, "I wonder if the object affords clicking.

"Affordances this, affordances that. And no data, just opinion. Yikes! What had I unleashed upon the world? "No!" I screamed, and out came this note. I don't know if it changed anyone's minds, but it brought the CHI-Web discussion to a halt. (Norman, 1999)

Thus, the concept of psychogeographical contours is preferred here, leading to the discussion of the instruments in the portfolio as topographies (see Chapter 4). Similar notions are being explored elsewhere. Iain Borden (1998), for example, invokes the perspective of the skateboarder in order to provide a psychogeographical critique of urban architecture. He describes how skaters perceive the city as a series of connected and navigable paths through 3-D space. This perspective, he argues, can help others to consider the built environment and its possibilities differently, and to gain new insights. This may be compared to the Tudorian notion of the "inside" (i.e. privileged) perspective of the designer-performer discussed in the previous chapter. It is therefore possible to see how the designer-performer may see the possibilities of, and experience, an instrument-topology differently to the designer, composer, performer, or audience (etc.). This also directly relates to the instruments in the portfolio being tested from more than one perspective, so as to gain multi-faceted insight and understanding (see Chapter 1).

## **Long-term Engagement, Learning, and Mastery**

While humans would appear to possess an innate capacity for making music

(Paradiso, 1997; Ball, 2010, viii), only a small number of instrument designs are successful and enduring. In general, these instruments tend to combine some degree of initial accessibility with possibilities of sufficient depth to keep the musician engaged over the long term (Jordà, 2005). For some people at least (instruments are still, at least in part, a matter of personal taste), the guitar is an example of such an instrument. While it can be picked up and played very quickly; in the case of the Jesus and Mary Chain, simply by holding it up to an amplifier and letting it feed back (Abebe, 2006), the investment of time reveals subtle and extensive additional possibilities. The restlessly inventive Derek Bailey, for example, found enough to sustain his interest for more than 60 years after he started (Toop, 2006).

If, by comparison, digital instruments provide few examples of long-term engagement, the situation is more complex than it may initially appear. There is often a tendency among designer-performers (and, to a lesser extent, the end users of commercial hardware) to constantly update their instruments. Tudor exemplifies this tendency more than most. While his work displays considerable dedication to the field of live electronics, two issues hamper the assessment of learning, development over time, and (potential) progress towards mastery:

- each instrument-composition rarely appeared in the same configuration twice (see Chapter 2);
- by default, each new composition is also a new and sometimes radically different instrument. Therefore skills and abilities may not be continued or sustained from one case to the next.

Similar issues are present in the work of Behrman, Lucier, and Mumma (contemporaries of Tudor), as well as Collins, Möslang, and Richards, among others. Added to this is the planned obsolescence of electronic and digital technologies (musical or otherwise). Even if the musician wishes to continue playing a certain

instrument, technologies fail and spare parts become increasingly hard to come by after the demise of the wider market (see, for example, Micronaut Particulate, 2011).

Nevertheless, there are at least a few examples of extended periods of engagement with digital instruments whose capabilities have been purposefully fixed or frozen.<sup>45</sup> These include Waisvisz (1985) and The Hands and Gehlhaar (1991) and the SOUND=SPACE system. Moreover, if digital instruments currently appear underwhelming in terms of their adoption and long term use, there is cause for optimism, for even the most successful acoustic instruments are imperfect (Jordà, 2005). For example, quietly and over extended periods of time, their designs can take their toll on the body of the performer. For example:

Many musicians suffer from serious health problems due to many years of intense practicing. Until fairly recently this was a hidden problem, and no training was provided for musicians on how to look after their body and how to prevent injury. There are now specialist medical clinics for musicians to attend, and an analysis of 1046 musicians seen at such a clinic of the British Association for Performing Arts Medicine (BAPAM) showed that just over half suffered from problems due to poor posture, tense neck and shoulder muscles, inappropriate practice regimes, lack of fitness and stress. (van der Linden *et al.*, 2011, p. 2)

As awareness of these issues increases, the appeal of digital instruments would appear likely to increase, for they can be designed around the needs of performer rather than the needs of acoustic sound generation.

Nevertheless, in spite of their imperfections, it is apparent that, at a personal level, traditional instruments can be intoxicatingly seductive. My own musical beginnings are perhaps a case in point. While I found learning the trumpet pleasant, it failed to captivate me, and I would practise for only a few hours per week. The

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<sup>45</sup> i.e. instruments that remain unchanged or unmodified over time.

electric guitar meanwhile; if an unlikely match for my physical abilities,<sup>46</sup> hooked almost instantly. Captivated by its seductive (yet ultimately destructive) loudness,<sup>47</sup> I would practise in my garage for several hours each day. Although it is difficult to pinpoint why, it is clear that the guitar captured my interest more emphatically than the trumpet. Thus, while the aim is not to imitate (the form, capabilities, or music of) acoustic instruments but to exploit the specific potentials of the digital, it may be necessary to foster similarly deep-rooted attachments if the latter aim is to be achieved: the need for practice is one thing that that is unlikely to change. Research indicates that extensive, sustained practice is more important than innate talent in determining the development of musicians (regardless of the instruments they play) (Cope and Smith, 1997).

We live in a culture in which many people seek instant, or at least fairly quick, gratification. Learning a musical instrument is a long-term undertaking based on the idea of delayed gratification. That is to say, a lot of work usually needs to go in before very much will come out. (ABRSM, 2011)

Fortunately, while learning to play a musical instrument is challenging (and at times outright difficult), as Csikszentmihalyi (1991, p. 4) suggests, it need not be drudgery. Indeed, for some people, learning to play a musical instrument is a substantial source of pleasure (it is all too easy to lose sight of this in the context of academic research).

While Jordà (2005) emphasises that learning may be non-linear, the notion of advancing (albeit perhaps unevenly) towards mastery is consistently present in the literature. For example:

Just as a painter must develop fine control over a paintbrush to make a rendition of a beautiful landscape, a musician trains his hands to achieve

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<sup>46</sup> It was not immediately apparent how I should go about even holding a plectrum.

<sup>47</sup> See, for example, Christian Meyer-Bisch (1996) for a discussion of the auditory damage caused by loud music.

mastery over his instrument to make beautiful music. (UA, 2011)

Expert musical performance is not just a matter of technical motor skill, it also requires the ability to generate expressively different performances of the same piece of music according to the nature of intended structural and emotional communication. (Sloboda, 2000, p. 397)

Despite differences in interpretation, another recurring theme is that mastery can only be attained through sustained practice (i.e. a considerable investment of time):

it is unlikely that first time players have the expectation of becoming expert players on any musical instrument. [...] Over time and with practice, a player can continue to refine their range of musical expression and become an expert (Blaine and Fels, 2003, p. 413)

Another approach is for experienced performers to dedicate the time necessary to develop virtuosic mastery of a new interface. This often requires years of dedication to a particular interface, but the rewards of such dedication are demonstrated by performers such as Laetitia Sonami and Michel Waisvisz (and of course, in the pre-computer age, therein virtuosa Clara Rockmore). (Dobrian and Koppelman, 2006, p. 281)

This relates to the notion that, regardless of the domain in question, around 10,000 hours of practice is necessary to master any given task or skill (Gladwell, 2008, p. 40). Nevertheless, additional factors also appear to be of some importance, including the consistency of practice and the time of day practice takes place (Sloboda *et al.*, 1996).

If the importance of effort in relation to expression was discussed earlier in this chapter, mastery is a related and somewhat complementary notion. It is seen by numerous authors to be intrinsic to expressive potential (Blaine and Fels, 2003; Porat,

2011).

musical expression is something that requires mastery of an instrument before subtlety can be achieved. Over time and with practice, a player can continue to refine their range of musical expression and become an expert. (Blaine and Fels, 2003, p. 414)

Thus, if the role of effort is one of amplification, the role of mastery can be considered one of enablement. Together they form an expressive chain (see Fig. 11):

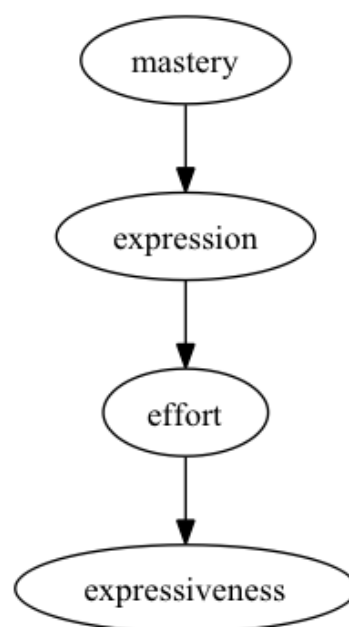


Fig. 11. The expressive chain.

While the term is sometimes used in a binary manner (i.e. a person has mastered x and y), mastery is not simply a threshold that must be crossed in order for expression to exist, but a variable that; along with the limitations of the human body, perception, and instrument design, determines the expressive range of the performer-instrument combination. Thus, if it is possible for a complete novice to produce expressive music, mastery allows for more sophisticated and varied expressive possibilities (Jordà, 2005; Vallis *et al.*, 2011).



While electronic and digital instruments do not prohibit (and may not even diminish) the possibility of mastery, for fields that encompass the Tudor circuits and numerous BCIs, traditional notions of mastery, rooted in the development of physical skill and dexterity, may be less appropriate (see the discussion of effort earlier in this chapter).

I try to find out what's there – not to make it do what I want, but to release what's there. The object should teach you what it wants to hear. (Tudor and Schonfeld, 2004, p. 25)

The live electronics of Tudor (and others such as Mumma and Behrman) can be seen to exemplify a different and perhaps more suitable understanding of mastery. This is no longer so heavily based on physical abilities that enable the spontaneous expression of thoughts or emotions, but on (mental) abilities that enable the performer to react and respond to a sometimes capricious instrument as they elucidate its embedded potentials (Paine, 2009). In the case of designer-performers such as Tudor, the blurring of the boundaries between design, composition, and performer introduces an additional layer of complexity. In these cases (increasingly common in the digital domain), mastery can be considered as the capacity of the designer-performer to express their own compositional (i.e. non-real-time) construction through (real-time) performance. Both circumstances dictate that mastery be detached from notions of complete or absolute control. It is no longer a matter of precision, and concerns itself instead with anticipating the full range of possible instrumental responses and behaviours. It is clear that the role of the instrument is much more active, and perhaps more substantial. Only with this intuition is the performer able to steer the instrument while reacting to the unforeseen and unforeseeable. Without this, the performer is ill-prepared to ride the instrumental beast without falling off, their ego bruised. Indeed, part of this new kind of mastery may be a post-Cagean acceptance that all outcomes are valid. If, thereafter, no such falls are possible,

conventionally-trained musicians may find it difficult to let go of their education (and its associated preconceptions and conventions, etc.).

## Summary

The first part of the chapter explored the evolution of musical instruments since the introduction of electricity. Moving animatedly through the decades, it traced a path from the technological innovations of the Telharmonium, theremin, and Ondes Martenot, to the subsequent return to the keyboard, and on to the unstable live electronics of Tudor. These unpredictable home-made circuits were seen to embody a number of qualities (in terms of design and musical output) that could be considered more broadly desirable. These qualities were then used critically to engage with subsequent developments, from commercial analogue synthesisers and the widespread adoption of the MIDI protocol, and the arrival of the first dedicated interfaces for computer music performance. From there, the focus shifted to a critique of the contemporary digital musical instruments and the New Interfaces for Musical Expression (NIME) scene, and an overview of the parallel practices commonly known as laptop music performance and post-digital instruments.

Informed by qualities identified as salient and desirable (earlier in the chapter), the second part of the chapter proposed an initial and sometimes personal framework by which Tudorian digital musical instruments can be considered, discussed, and ultimately designed. It included the following aspects:

- Emergence
- Nuance
- Skill and skilling
- Plasticity and meta-plasticity

- Expression, expressiveness, and spectacle
- The human turn
- (The nature of) experience
- Long-term engagement, learning, and mastery

It has been emphasised from the outset of this thesis that the intended role of the framework is not to impose fixed guidelines but to instead offer more flexible points of departure that can inform and aid the development of new digital musical instruments. A series of seven such instruments are presented in Chapter 4, thereby synthesising theory and practice in relation to Tudorian digital musical instruments. The next chapter (Chapter 3) sets out the methodological basis for this work, with particular emphasis on the methods used in their design and evaluation.

# Chapter 3

## Methods and Methodologies

### Overview

This chapter begins by outlining the methodological frameworks developed by Adnan Marquez-Borbon *et al.* (2011) and Ian Whalley (2010). These are then expanded to encompass more adequately the design, implementation, and evaluation of the new digital musical instruments. While the methods used relate to aspects of more established fields such as music technology, musical performance, art and design, Human-Computer Interaction (HCI), and computer science, they are considered part of a single, distinct field; that of digital musical instruments. From there, the chapter has two broad parts. The first part focuses on the methodological approach to the design and implementation of the digital musical instruments in the portfolio; or, in other words, the pursuit of the instrumental qualities identified as desirable and then incorporated into a framework in Chapter 2. The second part of the methodology is concerned with how to evaluate the new digital musical instruments, with particular emphasis on their expressive potential. In essence, my own experiences as a designer-performer are supplemented with informal, small-scale user studies in the hope that these different perspectives can together offer more rounded insight into the instruments in question. Nevertheless, it must be remembered that this is still a very early point in the life of the instruments in question, and also that the numbers of users are small. Thus, the findings should always be considered initial and indicative, rather than as any kind of firm proof of the hypothesis stated in the introduction (Chapter 1).

## **Towards a Digital Musical Instrument Methodology**

Marquez-Borbon *et al.* (2011) identify four main methodological styles found in the work presented at the NIME conferences. These are:

- Retrospective taxonomies and frameworks
- Evaluation of newly-designed digital musical instruments
- Evaluation of existing digital musical instruments
- Evaluation of underlying technologies

If the evaluation of newly-designed digital musical instruments style is closest to the main aims of this research, it is important to remember that practices remain varied. However, to generalise greatly, the methods used may typically resemble those detailed by Whalley (2010, p. 257):

- programming a set of machine based generative music patches with internal mutating rules that could also learn from real-time external human input;
- mapping (in software) input/output parameters between human/instrument and machine agency;
- programming machine generative improvisation/real-time human input to musical outputs;
- system testing so that a participating musician could explore the musical possibilities of improvisation with the system.

While this offers a reasonable foundation, it makes no mention of how current work is informed by previous developments (and therefore risks repeating the mistakes of the past), does not provide a path from intention to implementation, and does not state how the instrument created could be evaluated. It also does not consider the

performance interface or performer-instrument interaction, and is therefore too software-centric in most cases. Above all else it is clear that more comprehensive, methods are needed. Thus, the methods employed in this research are extended, and can be summarised as:

- the development of new digital musical instruments based on the framework proposed in Chapter 2, according to a balanced approach that fosters a consistent instrumental experience;
- testing the new instruments through a combination of small-scale user studies, and more personal exploration of and reflection on their musical capabilities (i.e. mixed methods);
- presentation, analysis, and discussion of results. These are first considered on an instrument-by-instrument basis, then an attempt is made to look for trends and ponder their cross-correlation;
- refinement of designs and re-testing as necessary and appropriate.

The rest of this chapter will elaborate on the methods used, with the bare bones above fleshed out with detail.

## **Design and Implementation**

In implementing the digital musical instruments presented in the portfolio, two overlapping methods are utilised:

- modification
- sketching in hardware and software

In a musical context, the idea of modification is closely related to notions of hardware hacking (Collins, 2009) and circuit bending (Ghazala, 2006). However, the underlying impulse is much older, for tinkering is an important part of live electronics and the live electronic music tradition (see Chapter 2).

For Archer (2004), the appeal of modified technologies is that they can appear old and familiar while operating in new and unfamiliar ways. They are almost always paradoxical; a safe reminder of, or reference to their own past, while concurrently unpredictable and unstable (sometimes to the point of terminal malfunction). When it works well, modification is not only able to open up new practical possibilities, but also establish different and perhaps subversive conceptual narratives (Dunne and Raby, 2001). Thus, obsolete, discarded, or otherwise worthless technologies<sup>48</sup> can find their lifespan extended, sometimes performing roles quite radically different to those intended by the original designer.

While a degree of improvisation is involved, modifying a musical technology typically involves opening up the case, identifying points of interest on the circuit board, then soldering two or more points together, often adding potentiometers or switches as a means of control (Archer, 2004; Ghazala, 2006; Collins, 2009). The resulting instruments often tend to be purposely ramshackle or lo-fi in appearance (Richards, 2006). Largely coincidentally and in isolation, I had developed similar practices myself during my teenage years. Returning to these methods some six or seven years later while developing the mTable, Eden3 and ServoString instruments, they had assumed a new relevance given the work of Möslang (2004), Richards (2006), and Carter (2010a), among others.

Miniaturization, power-reduction and knowledge embedding enable smart components that abstract much of the low-level engineering complexity, while keeping the capabilities of the technology accessible and affordable to people outside of heavy industry. This has re-created the possibility of

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<sup>48</sup> Given the unpredictability of modification, valuable technologies are rarely used.

vernacular technology that can be built from smart parts. People who would otherwise be unable to directly engage with digital technology tools can now augment, manipulate, experiment, build, explore. In other words, sketch. (Kuniavsky, 2008)

Nevertheless, if modification is useful for quickly trying out ideas, and in some instances for creating entire instruments, its limits are rather hard edged and binary. On the one hand, it is often desirable to approach the threshold of terminal decline in search of unpredictability; for some, unpredictability is directly related to musical interest. On the other hand, getting too close to or crossing this threshold (which is often unknowable in advance) may cause a modified technology permanently to fail, or the process to simply become tiresomely inefficient. Thus, in the case of this research, the modification of existing technologies is combined with (and for the most part superseded by) another method, that of sketching in hardware and software. This is an extension of the notion of sketching in hardware described by Mike Kuniavsky (2008), Robert Kowalski (2009), and Camille Moussette and Fabricio Dore (2010), closely tied to the notion of physical computing developed by Tom Igoe and Dan O'Sullivan (2004). This research makes explicit mention of the software side as a reminder that, despite the recent explosion of interest in the Arduino, Beagleboard and Raspberry Pi platforms (Gibb, 2010), the relatively fixed configurations of hardware cannot match the flexibility and versatility of software.

Each method has its own role, intent, qualities and purposes (Moussette and Dore, 2010). However, these are not necessarily discrete differences but a series of overlapping possibilities and limitations that Bill Buxton (2007; Greenberg and Buxton, 2008) terms the "sketch to prototype continuum". In the case of this research, perhaps the most important difference is that sketching makes no claims about the possibility of subsequent larger-scale production. While a prototype is seen to preempt a final production design, a sketch may eventually lead to a mass-produced product this is not assumed.



The Arduino platform represents an obvious choice of hardware for sketching: it is low cost, widely available, easy to use and integrate with other systems, and has numerous specialised forms (Nano, Mini, Mega, etc.). Perhaps the only immediately obvious limitation of the platform is the rate at which the sensors can be polled; while still acceptable in many situations, serial data rates are much slower than audio sampling rates.

On the software side the choice is more extensive and therefore more difficult, for many software tools are able to create real-time musical systems. These include Max, Pd (Puckette, 2006), SuperCollider, ChuckK, Impromptu, and RTCmix (Wang, 2008). Here, Max and Pd are adopted due to their capacity for interoperability, for they can comprehensively deal with exploratory combinations of audio, visuals, and external devices (Grierson, 2005). That my personal preference is for Max over Pd is primarily borne out of familiarity, but other software can be identified as less suitable on a number of grounds. For example, RTCmix lacks comparable tools for graphical/visual work, while SuperCollider is arguably less approachable for those without a computer science background (Grierson, 2005; Davey-J, 2008).

The use of Max in this research recalls the hub-like model developed by Brad Garton (2007), extended to include hardware. For example, Max is able to be interfaced with the Arduino using Maxuino: an open source firmware that enables bi-directional serial communication. This enables sensors to be read and servos, light-emitting diodes (LEDs), and motors (etc.) to be easily controlled from within Max. Input devices can be interfaced with Max directly using the Human Interface Device (HID) object, while devices can be connected indirectly over MIDI (Musical Instrument Digital Interface) and Open Sound Control (OSC).

Taken together, these methods enable the designers of digital musical instruments quickly to create functional sketches that can be informally tested early on in the development process. For example, the course of this research led to more than one thousand different sketches being developed. Many were closely related and differentiated by only minor changes to organisational structures or sound generation

algorithms, but each typically had its own strengths and weaknesses that only became apparent when the sketch was played (i.e. informally tested). Once issues became visible, improvements could be made and the next variation tested. Through this process of continual iteration, the strongest sketches would slowly emerge from a pool of similar designs over a period of days, weeks, or even months.

## Evaluation Methods

Like Whalley (2010, p. 257), Tudor offered notably little suggestion as to how new instruments could or should be evaluated. Until 2004 (just before his death) the Tudor circuits remained essentially the preserve of their creator (and thus risked being lost with their designer), and a significant part of their power is considered by Adams (1999) to derive from their impenetrable mystique. As Mumma notes:

it isn't the ingredients that determine the final glory of the meal – it's the mystery, magic, genius and daring of the chef. (Mumma, in Adams 1999)

Indeed, attempts at the formal evaluation of musical instruments are a relatively recent phenomenon. As Steven Gelineck and Sefania Serafin (2010) and Marquez-Borbon *et al.* (2011) note, such efforts have to date mainly been inspired by and borrowed from HCI methodologies (e.g. Wanderley and Orio, 2002; Kiefer, Collins and Fitzpatrick, 2008). However, formal methods have not come to dominate the NIME community, and informal methods continue to find favour (Stowell *et al.*, 2009). To this end, Marquez-Borbon *et al.* (2011) contend that:

part of the reason for the limited reach of formal studies is that it is not obvious how to conduct them in musical contexts; transplanting existing methods from HCI will not always work. In addition, reliable generative

frameworks are difficult to validate, especially in a creative domain that lacks easily specifiable evaluative criteria. (Marquez-Borbon *et al.*, 2011, p. 373)

Indeed, the difficulty of validation in a domain that lacks definite criteria may explain why a significant number of the NIME submissions attempt no kind of evaluation at all (Stowell *et al.*, 2009) (i.e. they simply present the system).

In the case of this research, the testing of the new instruments plays a number of important roles. Firstly, by testing the instruments at a relatively early stage, user feedback and personal reflection are able to immediately inform subsequent revisions and new instrument designs. Second, by placing the instruments into the hands of other users, additional space for reflection is created on the part of the designer. In other words, by stepping back and observing how other users play the instruments, it is possible to discover things that, without this distance, may have gone unnoticed. Finally, while the data collected can only be considered initial and indicative, the instrument testing provides the primary means by which the framework from which they are derived can itself be (indirectly) tested, evaluated, and ultimately revised as its unsuitabilities become clear. Thus, this process of designing, testing, and evaluating is more markedly iterative than linear, and contains multiple feedback loops. These feedback loops often occur on vastly different timescales, for some discoveries take longer than others to be understood and incorporated back into the design framework.

A key focus of the testing is to evaluate the expressive potential and possibilities of the new instruments presented in the portfolio. Reflecting the notion that the research questions must inform and determine the evaluation methodology (Greenberg and Buxton, 2008), the informal, hedonic methodology proposed by Gelineck and Serafin (2010) is seen to provide an appropriate basis for their evaluation (and the evaluation of their expressiveness).

We wanted to explore methodologies related not so much to the performance or usability of the system (how well the user is able to perform specific tasks) but more the overall experience with the system dealing with softer hedonic qualities - for instance how well the user identifies with the instruments, whether they are inspiring to work with or how well the system supports musical exploration. (Gelineck and Serafin, 2010, pp. 4–5)

While Chapter 2 developed a Tudorian approach to musical expression, there remain certain similarities to how expression is understood in more traditional instrumental performance contexts. For example, expression continues to be highly subjective, and correspondingly slippery and difficult to pin down. It also remains closely tied to mastery (in an adjusted form), and the notion that the user must invest a substantial amount of time in an instrument before its expressive potential can be exploited (Jordà, 2005).<sup>49</sup> Thus, even if the performer must make only limited steps towards mastery (mastery is not binary) before she can start to use an instrument expressively, the restricted timeframe of this research (and the shorter timeframe still of the user studies) poses an evidential problem. As a result, this research should be considered only an initial exploration of the new instruments it presents, and a case can be made for their evaluation over considerably longer periods of time. For example, the theremin and Ondes Martenot were initially quite successful, but by the middle of the 20th century had fallen into relative obscurity (Hunt, 1999), before (to a modest extent) being rediscovered and played by a new generation of musicians in the 1990s and 2000s (surely related to the growth of online information).

The question of gesture is . . . crucial in music. It lies in the intersection of two axes: one that binds together an observable action (the gesture of the instrumentalist) and a mental representation (the fictive movements evoked

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<sup>49</sup> Regardless of the discipline or activity, it is commonly suggested that around 10,000 hours of concerted practice is necessary in order to attain this state.

by sound forms), and another one that establishes the interpreter (that produces the gestures) and the listener (who guesses, symbolizes and transforms them on an imaginary plane). (Delalande, in Miranda and Wanderley, 2006, p. 8)

One of the most challenging aspects of expression relates to expressive result, or what Wanderley (2001) terms *expressive gesture*, for this may not always relate to expressive intent. Particularly in the case of digital musical instruments, where the performance interface and means of sound generation are separated, causality of sound is rendered unreliable or even entirely dissolved. Thus, the framing of expression in terms of measurable, gestural focus proposed by Camurri *et al.* (2001) is not well suited to the digital musical instrument context, for it risks an unbalanced or incomplete view. In order to assess the more inward and personal thoughts of the performer, more subjective methods are required. Thus, reflective journals (Glaze, 2002), interviews, and questionnaires are all possible options, and indeed, all are widely adopted elsewhere (Gubrium and Holstein, 2002; Adams and Cox, 2008, p.17). A combination of reflective journal and questionnaire is adopted here; the former being used to record my own experiences, the latter to assess the experiences of other users (as a supplement to personal experience). The questionnaire is favoured over the interview as a means of collecting supplementary data due to its potential for greater consistency if the same questionnaire is used across all of the studies undertaken. This in turn means that data (and therefore the instruments they relate to) are able to be compared and contrasted. At the same time, it must be remembered that these data are inherently subjective and inevitably influenced (i.e. biased) by the small numbers of participants involved and the limited time frame of engagement. However, while reasonable measures are taken to reduce experimental bias as much as possible,<sup>50</sup> a degree of fallibility is considered acceptable for data that are both initial and only supplementary to the experiences of the designer-performer.

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<sup>50</sup> The reader is referred to Nicholas Eriksson *et al.*, (2010) for an overview of such measures. These include, for example, asking similar questions in a number of different ways.

If the notion of a pilot study (Tashakkori and Teddlie, 1998, p. 47) is one obvious point of reference (in terms of scale, the limitations incurred, and the point in the research programme when it may be undertaken), the study proposed here is subtly different in that it does not presume subsequent research will be scaled up (some instruments are created for a specific user) or quantitative (qualitative approaches may continue to be the most suitable, even when the forms of the instruments are more established), although more longitudinal research is likely to be more desirable. Nevertheless, both kinds of study have a broadly similar appeal, namely that small-scale evaluation methods offer considerable advantages over larger studies in terms of agility, cost, and the manageability of data, yet offer much the same potential for useful discovery. Indeed, Jakob Nielsen (2000) goes as far as to suggest that diminishing returns may render larger studies superfluous, for the effort expended is likely to be greater than what is gained:

As you add more and more users, you learn less and less because you will keep seeing the same things again and again. There is no real need to keep observing the same thing multiple times, and you will be very motivated to go back to the drawing board and redesign the site to eliminate the usability problems. After the fifth user, you are wasting your time by observing the same findings repeatedly but not learning much new. (Nielsen, 2000)

Nielsen thus directly recalls the "hallway methodology" developed by John Gould *et al.* (1987) in order to test an electronic display for the Montreal Olympic games. The hallway methodology relies on only five or six opportunistically-recruited participants to informally test a functional prototype, and aims to quickly give an indication of how the final artefact will perform. Because of this agility, the hallway methodology is particularly conducive to iterative design strategies, whereby multiple cycles of designing and testing may be undertaken before a final form is reached. It can therefore also be seen as sympathetic to the sketch-based approach to digital

musical instrument development outlined earlier in this chapter. Like most small scale evaluation methods the hallway methodology has some inherent limitations. These include being misled by inadequate amounts of data (van Teijlingen and Hundley, 2001), a possible lack of contextualisation (van der Bijl-Brouwer and Boess, 2010), and increased likelihood of an unrepresentative population (Caulton, 2001). Nevertheless, as with the use of the questionnaire, these limitations are considered acceptable in the context of this research where the findings of the studies are treated as initial and supplementary.

At this point it may be pertinent to note that the value of personal experience is often equally contested, particularly in other disciplines. For example, Judith Green and Nicky Britten (1998) state that in the sciences, personal experience is commonly dismissed as anecdotal, ungeneralisable, and a poor basis for decision-making. Yet in the arts, by contrast, personal experience has traditionally been revered and even considered singularly authoritative. Indeed, there are few better examples of this than the instruments of Tudor (Adams, 1999). The tack of this research project is that while personal reflection is considered primary, it is hoped that the combination of two different perspectives (the "inside" perspective of the designer-performer and the less-vested perspective of study participants) will help to develop a more rounded understanding (see Fig. 12).

This dual track could be considered an example of mixed methods. While not widely used in relation to digital musical instruments, mixed methods are quite common in other fields, most notably the social sciences (McVilly *et al.*, 2008). Their power stems primarily from the ability to combine data types and subsequent possibilities for confirmation or divergence (Jick, 1979). As the combinations of data are often multimodal, multi-faceted, or otherwise complex, care needs be taken to ensure they do not become vacuously smoothed and featureless. Thus, when this research deals with multiple perspectives, it makes no attempt to offer a single, definitive account, and rarely discusses the portfolio instruments in terms of a collective experience (all concerned are considered to speak only for themselves).

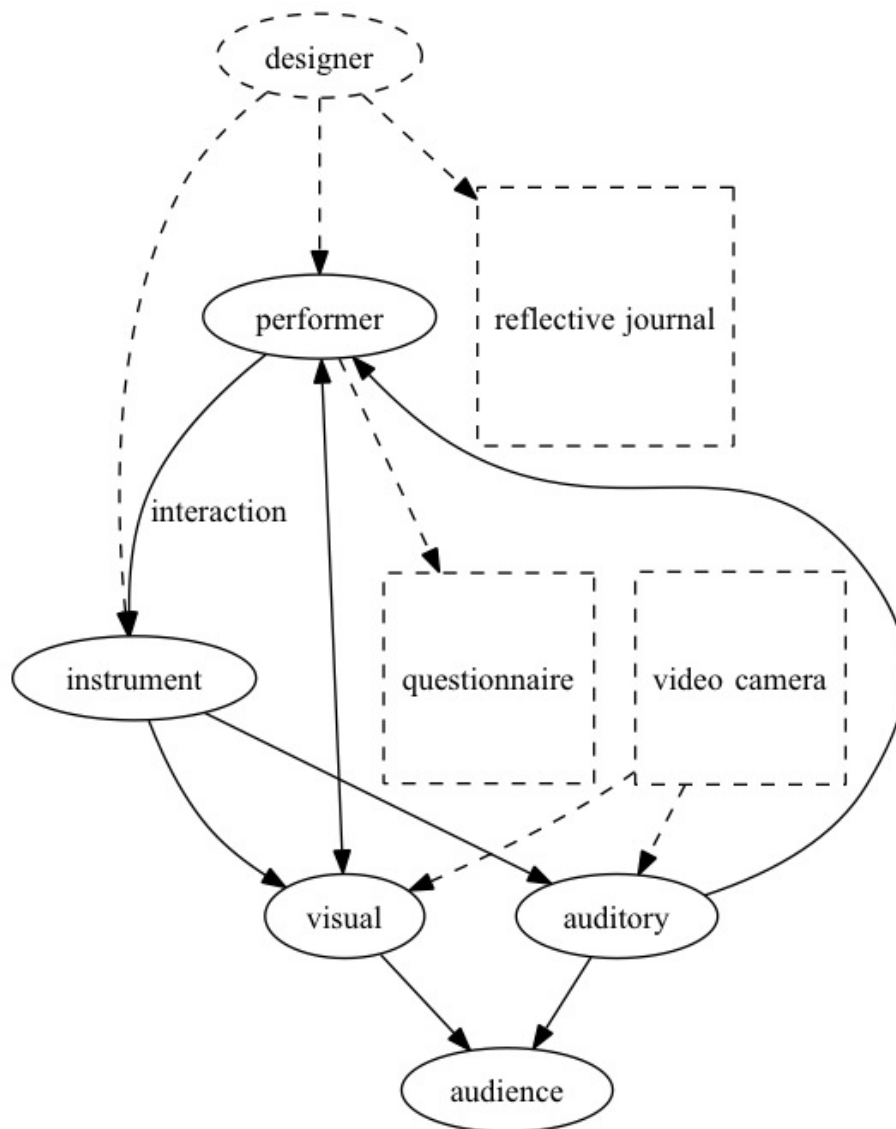


Fig. 12. The multi-faceted, multimodal nature of the evaluation methods.

Note that three of the instruments in the portfolio do not abide by this dual perspective and are evaluated solely by means of a reflective journal. The ServoString, for example, was conceived as a personal performance instrument (even though circumstances subsequently transpired to limit its use), while the Scanners and Eden3 projects that bookend the portfolio are treated as *meta-instruments*, or means by which the other instruments in the portfolio and digital musical instruments more generally can be discussed and understood.



## Pre-Study

To help determine the design and parameters of the user studies, an informal pre-study was carried out in advance. To ensure a supply of participants interested in new technologies, this was timed to coincide with a local Machinima workshop (see DVD example: *Early Work: Dream Machines*). Over two days, a selection of embryonic instruments were presented in an ad-hoc exhibition/cafe space. They were played by around 30 people, both male and female, with an age range of approximately 20 to 50 years. Only three of the participants had any significant previous musical experience.

While any and all questions from participants were answered, no instructions on how best to play the instruments were provided, and the sessions were essentially open-ended in terms of their aims and durations; participants could explore the instruments however they wished. It was soon apparent that the environment was far from ideal: distractions were many, and participants would tend to arrive in groups, stay for ten or fifteen minutes then move on. It was therefore decided that subsequent studies should happen in the more controllable conditions of a laboratory, where participants could be admitted one-by-one, interruptions could be reduced, and observations and recordings more readily and reliably made. After their session, each participant in the pre-study was invited to complete a questionnaire that aimed to assess both their overall experiences and what Roel Vertegaal, Tamas Ungvary and Michael Kieslinger (1996) term "attitude towards the system". Some changes were found to be necessary here too, and based on the suggestions of Ellen Taylor-Powell (1998), improvements were made to the structure and phrasing of some questions. This resulted in the canonical questionnaire form used across all subsequent studies (see Appendix B).

## Study Design

The general design of the user studies shall now be outlined. Although the tasks are different, the procedure is similar to that proposed and tested by Simon Holland *et al.* (2010; 2011). A small number of instrument-specific departures from this scheme are detailed where appropriate in Chapter 4. For instance, by the time the iPad Topographies had been implemented, I had developed an additional means of visualising the user interaction. As this built upon the existing basis of evaluation and did not significantly compromise the consistency of the studies, it was considered a useful additional tool.

We believe people learn to do things not by reading about how to do them,  
but by observing and doing. (Gould *et al.*, 1987, p. 764)

In order to recruit participants, potential subjects were first approached verbally and then given further information via email if interested (see Fig. 13). Appointments were then made at mutually convenient times. Every effort was made to ensure fair play. No financial or material incentives were used to encourage participation, and participants were treated in an equal manner. For example, care was taken to use neutral, non-gender-specific language, and to make the studies accessible to those with disabilities. Indeed, no interested parties were turned away, although this did mean that the number of participants varied between studies from three to eleven, depending on subject interest and availability.

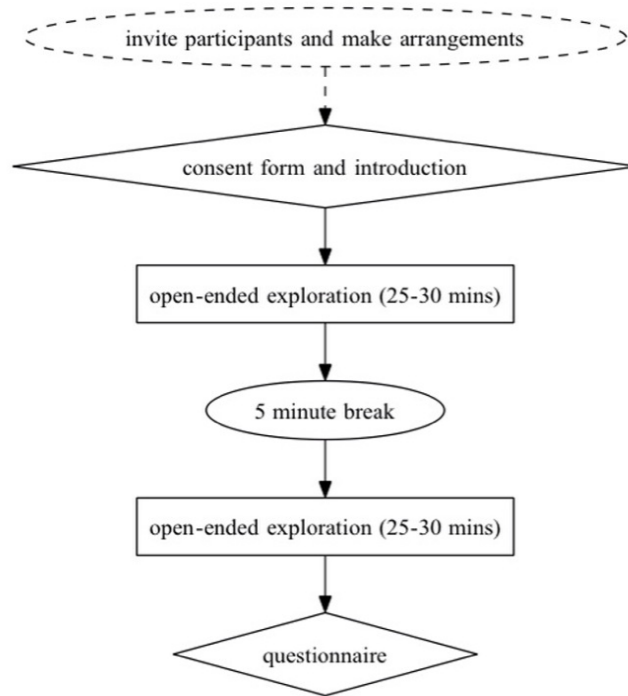


Fig. 13. The design of the user study.

The purpose and nature of both the study and the larger research project was reiterated to each participant as they arrived at the laboratory. Time was then allocated to carefully read and sign the consent form, with participant understanding also checked verbally. It was emphasised throughout that the participant could choose to withdraw consent at any time and without penalty. Participants were not provided with details of the instruments in advance, and so at this point the relevant digital musical instrument was introduced. Where appropriate, individual topographies were also allocated on a random basis. After a brief introduction to the specifics of the instrument, an acclimatisation period was provided for participants to set up and become comfortable. With most of the instruments participants had the choice of sitting or standing. The rest of the session (approximately one hour duration) was split in two, with a short break for refreshments at the halfway point. In a departure from the conventions of HCI, the set task is open-ended in that it essentially has no predetermined (or measurable) purpose or goals. Instead, participants are simply invited to:

explore the possibilities of the instrument in whatever way you wish.

Participants were overtly and directly observed (in the sense of Godwin and Chambers, 2009) during the task, and notes taken. The observer was positioned at the perimeter of the room to reduce their obtrusiveness, but the subject could still ask questions if desired. Finally, the sessions were recorded for subsequent review and analysis. As with the pre-study, at the end of the session, participants were asked to fill in a questionnaire (see Appendix B). No time limit was placed on this activity, and the participant was able to complete the questionnaire without interruption or interference from the researcher.

As mentioned earlier in this chapter, the user studies aim to evaluate the instruments in terms of relatively hedonic criteria (Gelineck and Serafin, 2010). However, traditional usability testing focuses on the ability of an object to meet measurably its intended purpose (Barnum, 2002). As Jeffrey Rubin and Dana Chisnell (2008, p. 21) describe, subject performance is typically assessed in four different areas:

- efficiency;
- accuracy;
- recall;
- emotional response.

It is clear that these areas are not compatible with the more hedonic focus of this research. Thus, the areas of enquiry targeted by the user study are refocussed to reflect the following performer-instrument qualities:

- engagement, learning, and mastery;
- expressiveness;

- efficiency of gesture.

The extended discussion of these aspects (collectively the Tudorian model that underpins this research project) forms the basis of Chapter 3 of this thesis.

## **Results Analysis and Interpretation**

The data generated by this research (being mainly qualitative) is not always clear cut, and so its interpretation is often subjective. This innate subjectiveness, combined with the small scale of the user studies, and uncertainty as to how to best synthesise the outcomes of the mixed methods (there are surely no fixed ratios), means that the findings can only be considered indicative and a useful supplement to personal reflection.

Questionnaire data were exported from the online form and imported into a standard Office spreadsheet format (.xls). Before analysis, the data were checked for normality and erroneous cells were removed. Formulae were then added into the spreadsheet to calculate the arithmetic mean (Mean) and standard deviation (SD) for each part of the data set (see Appendix C). Due to the small population size, after Robert Groves *et al.* (2004), a weighting is not applied to the Mean. The results were analysed manually, and written up in long form. Interesting (i.e. significantly positive or negative) sections were then extracted and refined for presentation and discussion in the thesis.

In parallel to this, the audio and video recordings were examined for moments of interest. Any salient sections were noted and then extracted for further review. The questionnaire results were compared with the audiovisual recordings, my notes, and the reflective journal in order to provide a more rounded view. In the synthesis, these aspects are not assigned any particular hierarchy, but are instead considered part of a

holistic environment of data. Within this environment, correlations and discrepancies between different data types are considered for their particular points of potential interest.

## Summary

The frameworks developed by Marquez-Borbon *et al.* (2011) and Whalley (2010) have been extended to encompass the design, implementation, and evaluation of new, Tudor-inspired digital musical instruments. The first two aspects (design and implementation) involve a combination of modification and sketching in hardware and software, while the latter aspect (evaluation) supplements my own experiences as a designer-performer with observation and feedback gathered from small-scale user studies. Particular emphasis has been placed on the methods used to evaluate the *expressive possibilities* of the new instruments, and some of the challenges posed by the evaluation methods have been detailed.

# Chapter 4

## Putting Theory into Practice

### Overview

Building on the foundations provided in the previous chapters, this chapter presents and discusses the seven digital musical instruments which constitute the practical portfolio. These are:

- Scanners (Blocks, Seeds, and Rewire topographies);
- the mTable (Drift, Multi, Anti, and Quarters topographies);
- iPad Topographies (Drone, Contra 2, Brenschluss, Qu4rters 2, and Androids topographies);
- ServoString;
- Vanishing Point;
- DelayNet;
- Eden 3.

Following a brief discussion of earlier and related work, each project is presented in turn. After Bongers (2006), the seven instruments are presented in ascending order of scale, from the intimate to the environmental. There are two main reasons for this diversity. First, it is a conscious attempt to push at and explore the boundaries of the framework, for it is not yet clear where these may be situated. Second, given that digital musical instruments can take essentially any form, it is an attempt to explore more generally what the most productive forms may be in terms of the performer-instrument relationship and other aspects such as playability. The exception to this

ordering by scale is that the iPad Topographies follow the mTable work, for the two are so directly (chronologically) related that to do otherwise would be nonsensical. A consistent structure is applied throughout. In each case the instrument is first introduced and briefly detailed, then its character and nature discussed. Where appropriate this is then followed by an overview of the small-scale user study<sup>51</sup> and the presentation and subsequent discussion of the results. The last part of the chapter begins to bring these findings together, setting the scene for the drawing of conclusions in the final chapter.

## Early and Other Work

In order to provide additional context, before moving on to discuss the instruments in the portfolio I shall provide a brief overview of works which are not included.

The Virtual Squares of World Culture installation (TMA Hellerau *et al.*, 2006), for example (see Fig. 14), tilted my practice away from the use of pre-composed samples (see DVD example: Early Work: Global Squares 1) in favour of generative systems (see DVD example: Early Work: Global Squares 2). Nevertheless, my contribution to the project was mainly technical, and thus it is not included in the main portfolio.

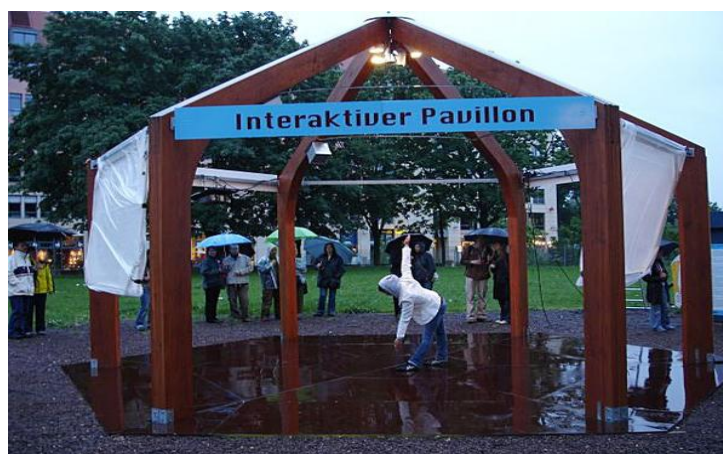


Fig. 14. The Virtual Squares of World Culture (Dresden Pavilion).

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<sup>51</sup> Instrument-specific deviations from the methods set out in Chapter 1 are detailed where necessary.



The Physical Sequencer (Guerriero, Mudd and Dalglish, 2009) (see Fig. 15), a vertical, 8x7 array of light sensors played in a non-contact manner, is not included for similar reasons.



Fig. 15. The Physical Sequencer (The Cube, Manchester).

The Footfall installation meanwhile (see Fig. 16), although crucial in developing both the notion of a topography and my use of synthesised sounds (see DVD example: Early Work: Footfall), is superseded by the mTable and iPad Topographies.



Fig. 16. The Footfall installation (the Lanchester Gallery, Coventry).

The more recent collaborative works Haptic Drum Kit (Holland *et al.*, 2010; Bouwer,

Dalgleish and Holland, 2011a) (see Fig. 17), Whole Body Harmony Space (Holland *et al.*, 2011; Bouwer, Dalgleish and Holland, 2011b), and Alexander Sleeve (van der Linden *et al.*, 2011) are tools for music learning rather than performance and are therefore not considered in detail here. However, elements of their code are present in almost all of the portfolio instruments.



Fig. 17. The Haptic Drum Kit at 40 Years of The Open University, Walton Hall.

A large number of sketches were started that, for various reasons, were not continued (see Fig. 18). While those directly relevant to the portfolio instruments will be discussed, many others are left out of this thesis and accompanying portfolio.



Fig. 18. The Plank: an initial instrument concept that was later discontinued.

Finally there is the mLibrary, a collection of abstractions and patches (see Appendix D) for Max and Pd, created during the development of the instruments in the portfolio. These files are made available online in the hope that they may be useful to others,<sup>52</sup> but as they relate only tangentially to the narrative of this thesis there is not room to consider them more fully here. With this brief discussion of early, related, and other work in place, the seven digital musical instruments that constitute the main body of the practical portfolio will now be presented.

## **Scanners BCI Instrument**

Composer-performers, particularly those in the live electronics tradition, have long been interested in the prospect of brain-controlled music (Roads, 1996, pp. 617-659; Miranda and Boskamp, 2005). Aided by new technologies, the last decade has seen renewed and sustained interest from both HCI researchers (Miranda and Boskamp, 2005; Miranda and Matthias, 2009) and audiovisual artists (Grierson, 2005; 2008). Nevertheless, the appeal for the performer remains essentially the same: that intention can be so directly translated into technological action as to render the body unnecessary. From a more personal perspective, I entered into the Scanners work sceptical of the practical limitations of the technology. Nevertheless, the intimate yet drifting quality of brain-computer interaction represented enough of a departure from traditional instrumental paradigms to appeal as a starting point for a new digital musical instrument.

## **System Design**

Until relatively recently, BCIs were specialised medical and research tools. This has

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<sup>52</sup> They have been downloaded around 130 times each on average.

changed with the introduction of the OCZ NIA, Neurosky Mindset, and Emotiv EPOC systems intended for the video games and academic research markets. The Scanners instrument was initially built around an OCZ NIA headset, but the project was put on hold until the more capable and hackable Emotiv EPOC BCI became available.<sup>53</sup> The current form of Scanners consists of four main elements (see Fig. 20):

- an Emotiv EPOC BCI headset;
- the MindYourOSCs software bridge (Bitrayne, 2010);
- three different Max topographies;
- an optional visualisation of the real-time electroencephalography (EEG) data.

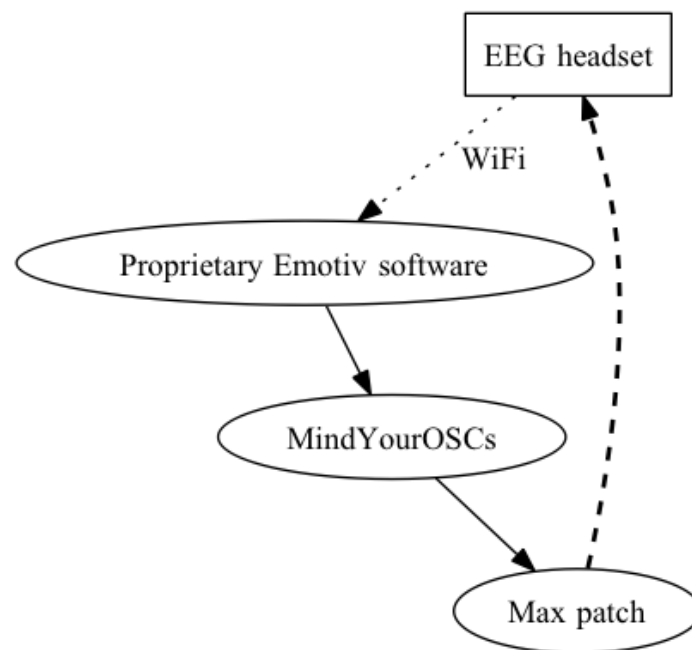


Fig. 19. Scanners system diagram (the thick dotted line shows bio-feedback).

The EPOC headset contains 16 electrodes that sit on the scalp in order to sense the EEG signals of the user. Fast Fourier Transform (FFT) analysis is then used to split

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<sup>53</sup> This took around 9 months longer than expected.

these signals into discrete frequency bands. The distribution of power between these bands implies certain states of mind (Miranda and Boskamp, 2005). In this case, the opposing states of concentration and relaxation are used.

The MindYourOSCs code acts as a software bridge, piping cooked (i.e. refined) FFT data into Max where they drive the chosen musical topography. To have the EEG data available in real-time and in an open format does much to make BCI technologies accessible for musicians and composers.<sup>54</sup>

## **Topographies**

Following the general overview of the Scanners instrument above, the Blocks, Seeds, and Rewire topographies will now be presented in more detail.

### **Blocks**

By far the simplest of the three topographies, Blocks explores a building block-like approach to musical performance. In a parody of popular laptop performance software such as Ableton Live, a track can be constructed in real-time from pre-composed interlocking and stackable audio loops (McGowan, 2010). A mirroring approach to mapping EEG signals to musical output (Holland, 2011) is adopted. Thus, when the EEG output implies a relaxed state of mind, sparse and minimal loops are played. Correspondingly, when the EEG output implies a state of focus, more complex loops are played. By learning to regulate and to some extent control their EEG output (i.e. achieving a kind of mastery of biofeedback), the performer is able to steer the evolution of the music. It is possible, for example, to create a sense of dramatic tension, or the perpetual cycle of ascension, climax, and release that typifies

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<sup>54</sup> This degree of interoperability was not typically possible in previous musical BCI systems.

many forms of electronic dance music.

## Seeds

The Seeds topography (see DVD example: Scanners: Seeds Topography usage) is more complex in its implementation, although like the Blocks topography its concept is relatively simple. The EEG output steers the selection process of a genetic algorithm (see Dulay, 1996; Biles and Miranda, 2007)<sup>55</sup> to favour one pool of chromosomes or another each time a new generation of offspring are spawned. Each chromosome (i.e. list) is randomly generated, but the first pool bounds list generation so as to produce smaller intervals between its elements, while the second pool bounds list generation so as to produce larger intervals between its elements. Both pools can contribute to offspring, but the size of the contribution is determined by the current EEG output. This time, what Holland (2011) terms a "homeostasis" approach to mapping is adopted. Thus, a relaxed state of mind tends to result in larger intervals (rough), while a focused state tends to result in smaller intervals (smooth). A mutation function, meanwhile, introduces a small amount of random data into each generation. The offspring chromosome (list) is then read into a sequencer, while also being placed back into the pool of chromosomes, and therefore persisting into the next generation. The sequencer steps through each value in the list in turn at a rate determined by a global metronome, thereby playing a melodic sequence. A simple diatonic accompaniment is generated from the first pitch in the sequence. When the end of the sequence is reached, a new offspring chromosome is spawned and the cycle begins again.

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<sup>55</sup> With the problem at hand being: find a musical sequence that reflects the state of mind of the performer at the given moment.

## Rewire

The NIME community has tended to focus on the externalisation and physicality of the performance interface, while mapping and sound generation aspects have typically remained hidden, existing only as computer code. For many observers this arrangement is impenetrable and problematic in terms of its reception (Stuart, 2003). In the parlance of Tudor, it could be said to limit inside understanding to those who are familiar with its abstract codes. Thus, by using a modular synthesiser to externalise mapping and sound generation, the Rewire patch attempts to make these aspects more tangible. Relegated to the role of bridge, the importance of the laptop is downplayed.

The EEG signals pertaining to concentration and relaxation are first passed into Max, then converted into control voltages by the Expert Sleepers ES-1 module and Silent Way plugin (Expert Sleepers 2010a; 2010b). Four identical control voltages are produced from each EEG parameter. The performer is able to map and remap these control voltages around the synthesiser in real-time using patch cables. The connections between the modules are clearly visible to the audience.

## Reflection and Discussion

Although the EPOC headset is not invasive in the manner of implanted BCIs (Lal *et al.*, 2005), it is still a somewhat intimate and uncomfortable experience. Thus, testing of the instrument was strictly informal and limited to myself plus two interested colleagues. While the intention was to explore the viability of a subsequent user study, the initial experiences of the instrument were not promising and therefore this did not take place.

Perhaps the most interesting aspect of the Scanners instrument is its interaction. The performer not only influences the music that is produced, but is also influenced



by this same output (i.e. there is a bio-feedback loop). The strangeness of this condition appears divisive, with the two participants commenting that:

the instrument fostered an unexpected degree of closeness, of intimacy.

At times I found it to be hugely frustrating. The lack of stability could be maddening as I struggled to regulate my [own] EEG output.

If I personally relished the unusual drifting, imprecise quality of the performer-instrument interaction, I found other, less easily resolved issues to be problematic. Performance spaces,<sup>56</sup> for example, are not often sympathetic to the kind of insular concentration needed to play the Scanners instrument. They tend to be noisy, hectic, and rushed, and therefore a BCI instrument is perhaps more suited to studio use than performance (see Fig. 20). This is further emphasised by the lack of innate visual cues and gesture: audiences are likely to consider BCI performances no less problematic than clerical laptop interaction (Cascone, 2000; Stuart 2003). The Rewire topography is a direct attempt to address this issue, but it cannot be considered a satisfactory solution, for the act of patching itself causes unwanted and uncontrollable peaks in the EEG output.



Fig. 20. The author performing with the Seeds patch.

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<sup>56</sup> Even in the expanded contemporary context that includes art galleries and nightclubs, as well as concert halls.



Relating to the initial premise of direct translation, the BCI remained resolutely cumbersome and external. At no point did the performer-instrument interaction feel natural or seamless. Curiously, I had a similar experience with prosthetics as a child in the 1990s. While my electromyography-controlled prosthetic arm was intended to offer intimate and precise control, it continued to feel detached and alien more than a year after it was fitted. Minute muscle movements quite accurately and repeatedly opened and closed a robotic hand, but my flesh felt remote and desensitised contained inside its cocoon-like structure. Only by abandoning the prosthesis entirely that I was able to learn to play the guitar. Not only was this sudden abundance of tactility and connectedness a cathartic experience for my 13-year-old self, but my thumb proved surprisingly adept at picking guitar strings. Yet, if the seductive effortlessness of brain-computer interaction risks the physical abilities of the body being overlooked, they have obvious applications for people who, because of disability for example, may not be able to manipulate more traditional and physical instruments.

## **Summary**

The Scanners instrument combines a commercially available BCI, an OSC software bridge (Bitrayne, 2010), and three Max topographies that act as exploratory musical examples. A paradox is apparent in that while the performer-instrument interaction carries the expectation of intimacy, the BCI can stubbornly resist internalisation and continue to feel extraneous to the performer-instrument relationship.

# The mTable

The mTable (see DVD example: mTable: mTable Overview) is a multi-touch surface rooted in my earlier experiments with light dependent resistor (LDR) arrays (Guerriero, Mudd and Dalglish, 2009), bi-directional LEDs,<sup>57</sup> and multi-touch pads. These exposed considerable limitations in terms of their surface area, speed, and accuracy, prompting me to look for more suitable methods. Crucially, information on how to design and build multi-touch systems had been made available online by the likes of the Natural User Interface (NUI) Group (2009) and the Music Technology Group at the Universitat Pompeu Fabra (Jordà, 2005). I therefore set out to build my own low cost multi-touch table as a development platform for software instruments.

## System Design

The mTable consists of the following generic hardware and software elements (see Fig. 21):

- a structural frame
- a PS3 Eye video camera modified for infrared (IR) light
- Community Core Vision (CCV) open source tracking software
- OSCulator software
- a multimedia projector

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<sup>57</sup> Based on Han (2006). Interestingly, a similar – but more tactile – model of interaction is offered by Overholt (2001).

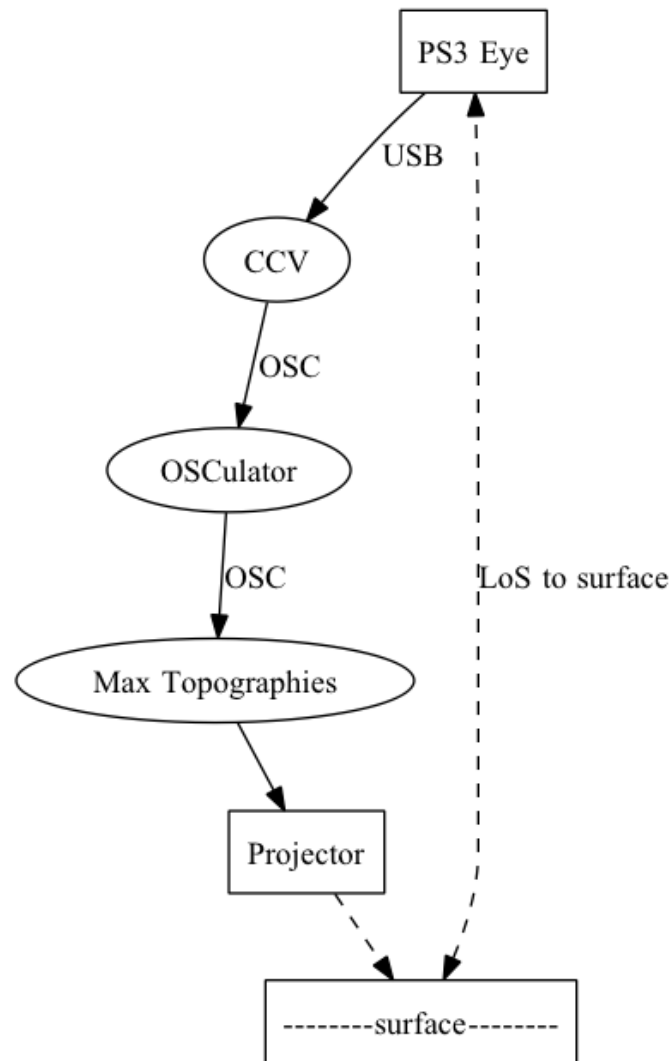


Fig. 21. The generic aspects of the mTable system.

While multi-touch technologies have been available since the late 1970s or early 1980s (Buxton, 2011), the last decade has seen renewed interest and the development of new methods. These include the Frustrated Total Internal Reflection (FTIR) technique developed by Jefferson Han (2006), the Diffuse Illumination (DI) technique implemented in the ReacTable (Jordà, 2005), and the capacitive detection technique implemented by Mitsubishi (Dietz and Leigh, 2001). Capacitive detection is difficult to implement in a DIY context, leaving the DI technique in which IR light is shined at the touch surface from below, and the FTIR technique in which rows of LEDs shine IR light into the edges of an acrylic sheet (NUI Group, 2009). The DI

technique is adopted for the mTable because of its simplicity and because it is able to track both fiducials<sup>58</sup> and fingertips (i.e. it is more flexible).

Based on the design outlined by Johannes Schöning *et al.* (2010), the 55x55cm surface consists of two layers of 10mm-thick acrylic sheet, with a layer of diffusion material placed between them. The surface is supported by a simple modular frame, its sides panelled to block out external light. A Sony PS3 Eye modified for IR use observes the surface from underneath the table, while an IR security floodlight positioned inside the frame offset from centre is used as a light source, improving the contrast of the image.

The images produced by the PS3 Eye are analysed by the CCV tracking software (NUI Group, 2008).<sup>59</sup> This sends OSC messages pertaining to blob (x,y) position, size, and angle to Max, passing through an OSCulator patch en route to ensure compatibility with the ReacTIVision computer vision software (Kaltenbrunner and Bencina, 2008) (see DVD example: mTable: General). The visual projection onto the underneath of the surface uses visible light, and therefore does not interfere with the IR-based tracking (see Fig. 22). This projection is optional, and the mTable can also be used in conjunction with a separate projection. The latter approach was adopted during the user study, with the suggestion that its head up model may be beneficial in situations where eye contact, for example between performers or performer and audience, may be important (Fredrickson, 1994).<sup>60</sup> It also makes for more robust lighting, tracking, and observation.

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58 These are machine-readable position markers.

59 ReacTIVision (Kaltenbrunner and Bencina, 2008) can also be used.

60 As Jordà (2005) notes, traditional instruments such as the guitar and piano are not usually played visually, but by touch.

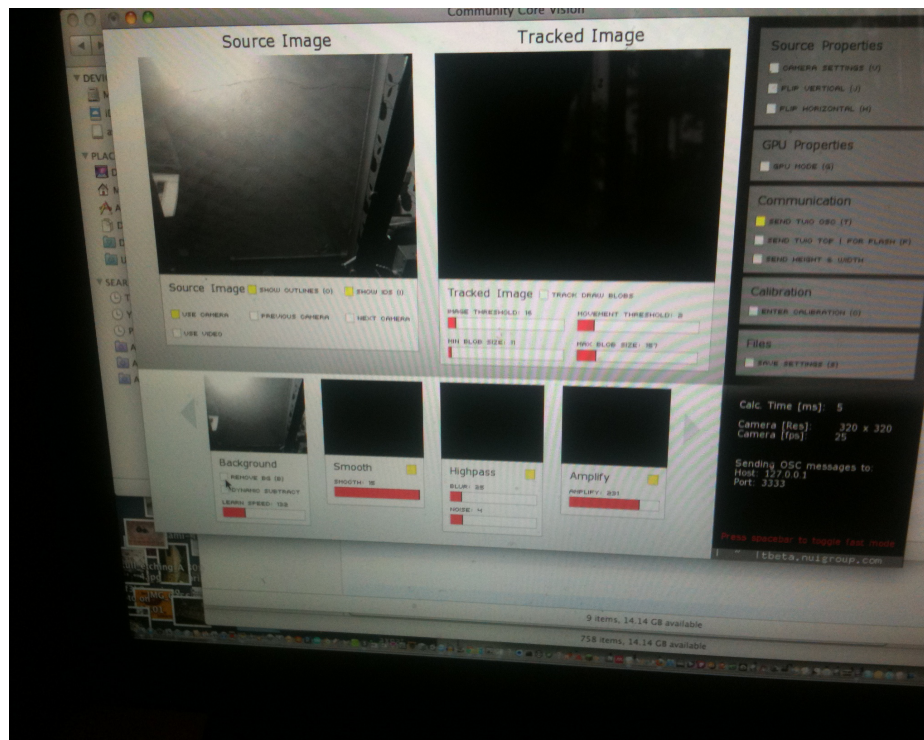


Fig. 22. The view of the video camera from underneath the mTable surface.

## Topographies

In order to explore the possibilities of the mTable platform, four different musical topographies were created. The nature of these topographies will now be detailed in turn.

### Drift

The Drift topography is a collection of four real-time samplers that possess instrument-like playback abilities.

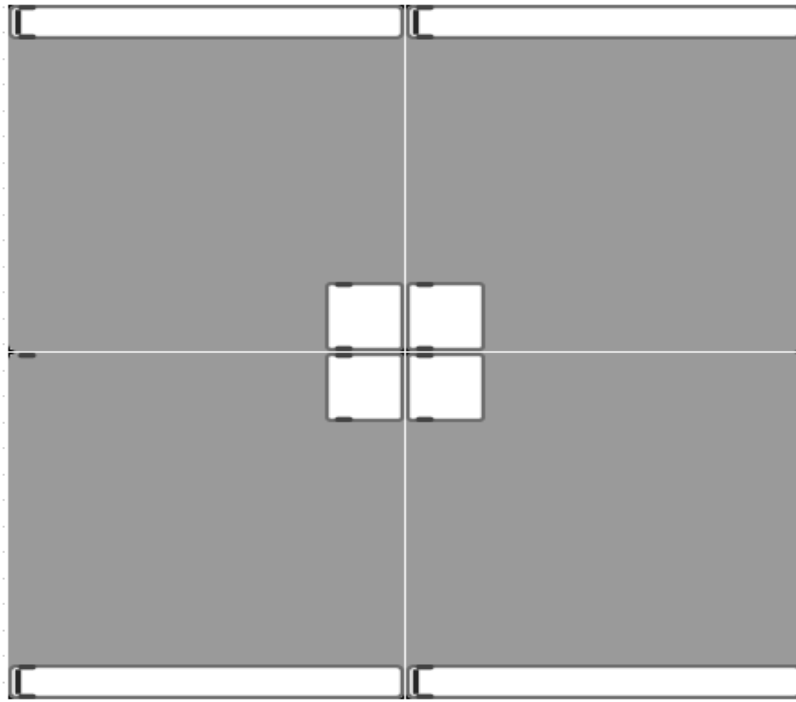


Fig. 23. The Drift topography graphical user interface (GUI).

Unlike the other mTable topographies, its sound sources are derived from its environment (i.e. captured in real-time by a microphone). At any time the microphone input can be recorded and stored in any (or all) of the four buffers. The lengths of the buffers are flexible and automatically adapt to input, but useful buffer lengths range from a few seconds to a few minutes in length. The moment recording is stopped any active sampler will switch modes and looping playback begins (similar to Berthaut, Desainte-Catherine and Hachet, 2010). The playback speed, expressed as a ratio of x:y axis position within one quarter of the table surface, is able to be controlled by the performer (see Fig. 23). A ratio smaller than 1:1 causes the direction of playback to reverse. As the source material collected is usually related, the overall effect is often less like playing four individual instruments than sculpting a single mass of sound.

## Multi

The intention of the Multi topography was to create an instrument that recalled the

economy and unpredictable behaviours of analogue electronic systems (Collins, 2011) while utilising the sound generation possibilities of the computer. Thus, on one level the Max patch is extremely simple. It consists of only four variable delay lines, plus feedback and reverb. But beyond this initial economy is a deceptive subtlety and complexity. As with the precariously balanced Tudor electronics, each delay line is sensitive to even tiny parameter changes. Varying the delay time by one millisecond will, under certain conditions, produce a wrenching shift in both timbre and pitch. Moreover, as the topography is based on changeable audio processes, its behaviours are (to some extent) dependent on previous actions and the current state of the system: a particular action may not always result in the same response or sound.

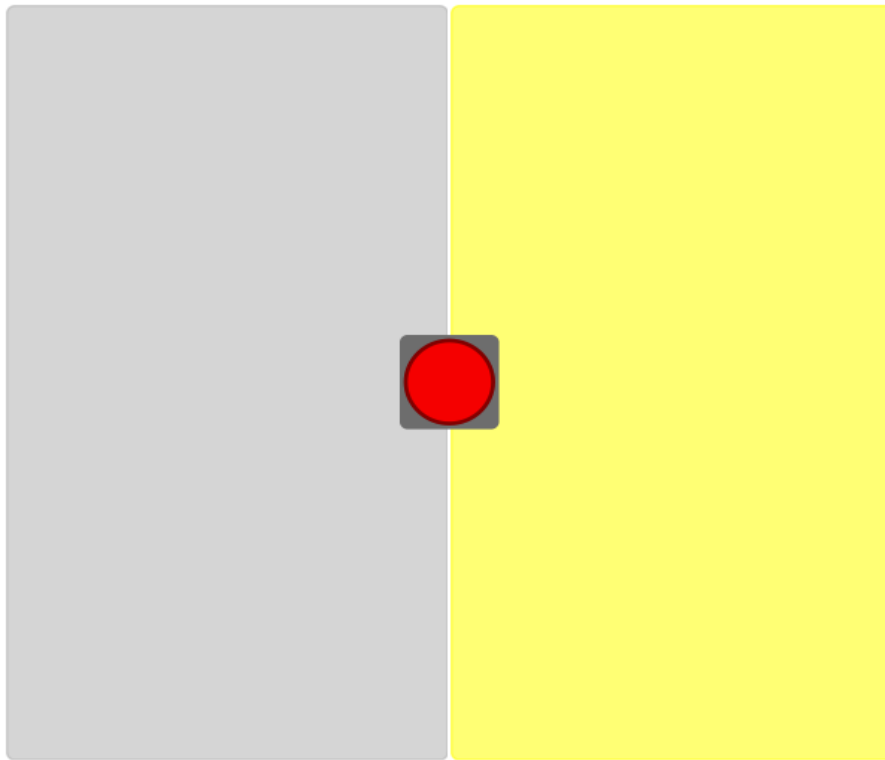


Fig. 24. The Multi topography GUI.

The nature of the control offered to the performer is strictly indirect, with the touch surface split along its centre into two zones. These are identical in shape and area, but mirrored horizontally, whereby position zero on the x axis starts at the centre line for both zones (see Fig. 24).

Interaction in the left zone influences the global tempo and the maximum rate of tempo change, while interaction in the right zone influences both the fundamental frequency of the drone and its harmonic construction. The intervals between constituent layers can range from unison to one octave difference. As with the Drift topography, the experience is of steering a single mass rather than four separate instruments. However, the Multi topography is much less stable than its counterpart, and often teeters right on the edge of control/uncontrol.

## **Anti**

The Anti topography (see Fig. 25) is influenced by so called Intelligent Dance Music (IDM) and the Autechre (1994) track *Flutter* in particular. Its dynamic, ever-changing beats, created to circumvent Tory rave legislation, are seen as a digital counterpart of Tudorian unpredictability.



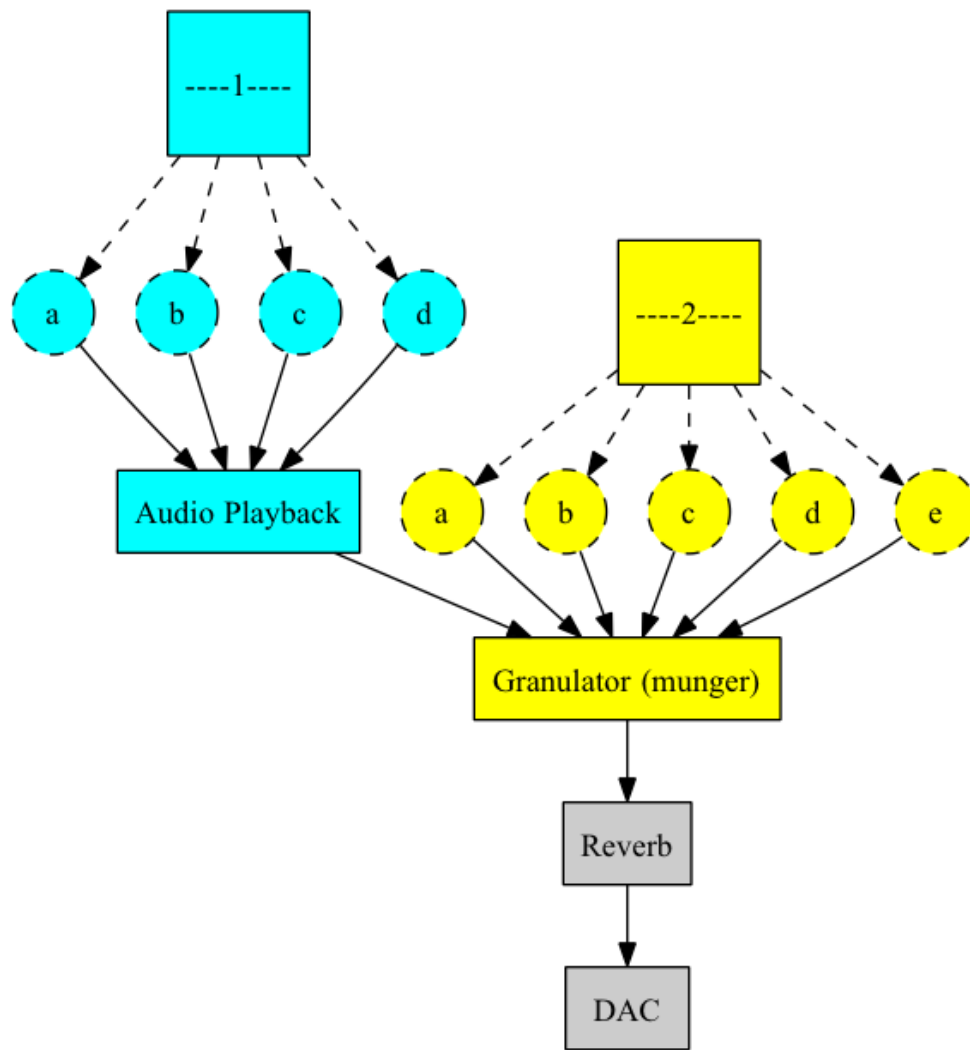


Fig. 25. System diagram for the Anti topography.

As with the Multi topography, there are two zones of interaction, but with the surface split from top to bottom rather than left to right. Each zone contains a bank of sliders (see Fig. 26). By drawing into these banks with his/her fingers, the performer is able to steer the rhythmic and melodic evolution of pliable musical structures. The upper bank relates to sample playback, looping, and pitch, while the lower bank relates to 16 granulation parameters developed by Dan Trueman and Luke DuBois (2001).

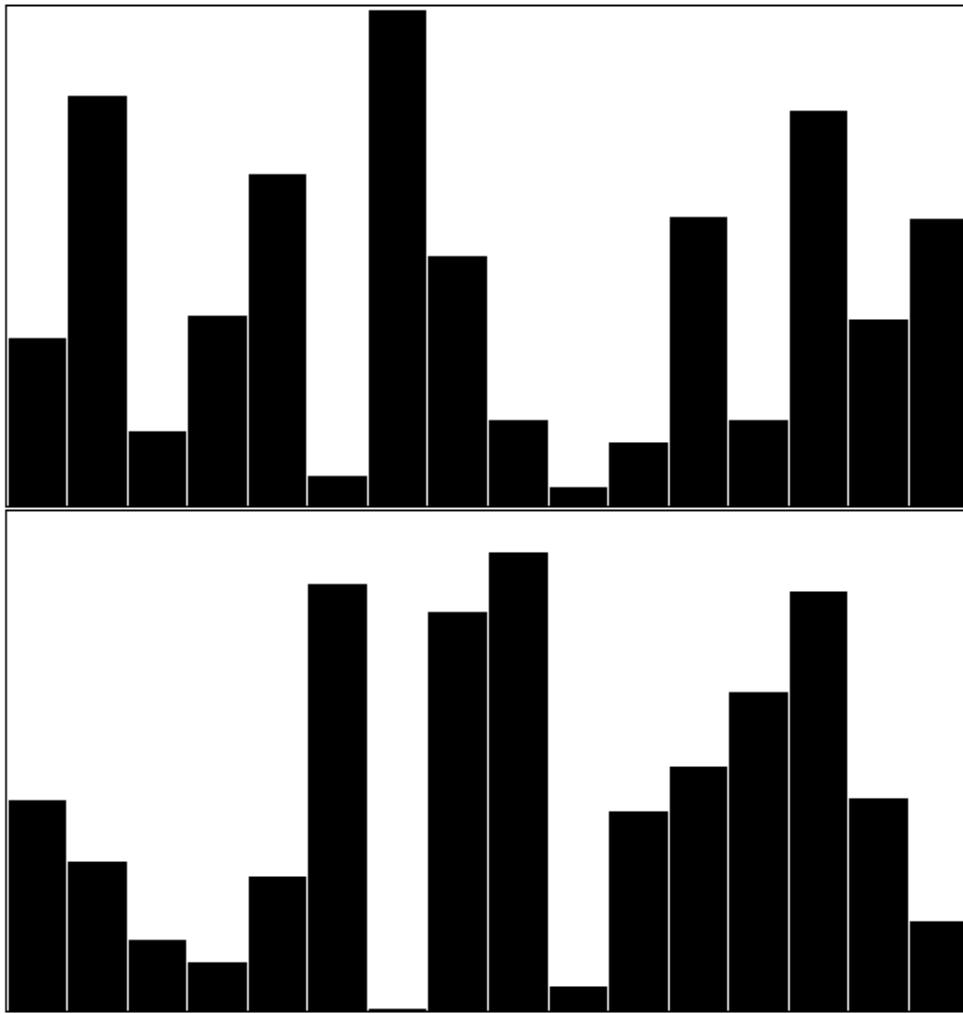


Fig. 26. The Anti topography GUI.

The influence the performer has over the topography is non-linear and unpredictable, and periods of silence are common before parameters slowly mesh and sound is produced. The threshold between sound and silence is often extremely small, and there can be a sense of treading water in an attempt to stay afloat as the instrument teeters on the edge of control.

## Qu4rters

The Qu4rters topography is a collection of four individual instruments (a kind of virtual quartet) under the influence of the performer (see Fig. 27). Even if in many

ways it is far removed from a traditional musical instrument, Qu4rters offers a more traditional instrumental paradigm in that the performer is able to shape *what* is played as well as *how* it is played, rather than the conducting paradigm offered by Mathews (Hunt, 1999).

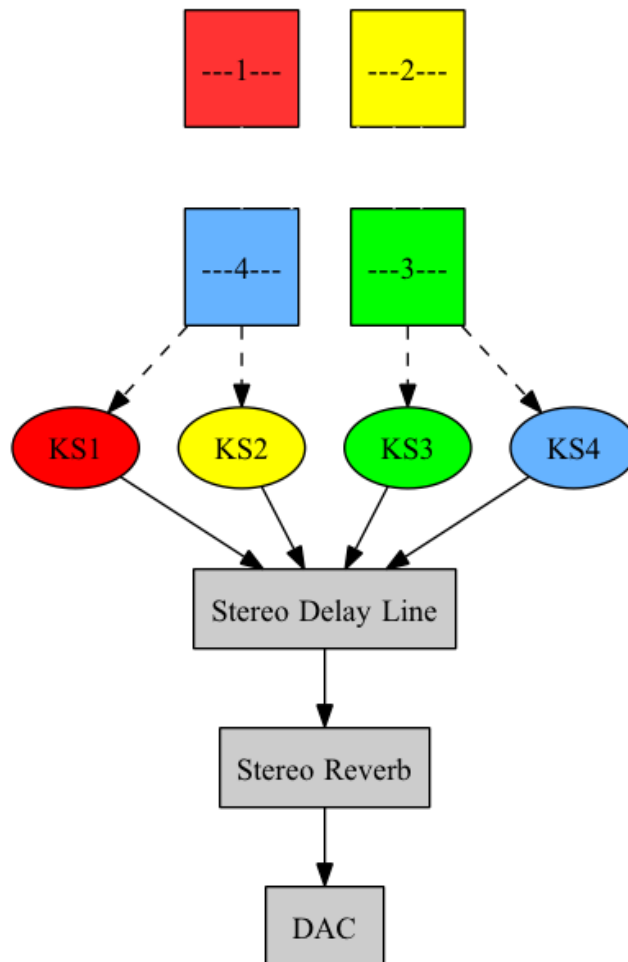


Fig. 27. System diagram for the Qu4rters topography.

As with the Drift topography, the interaction surface is split into four zones, with one instrument assigned to each zone. While the dimensions of the zones are identical, each zone contains a unique arrangement of circular nodes (see Fig. 28).

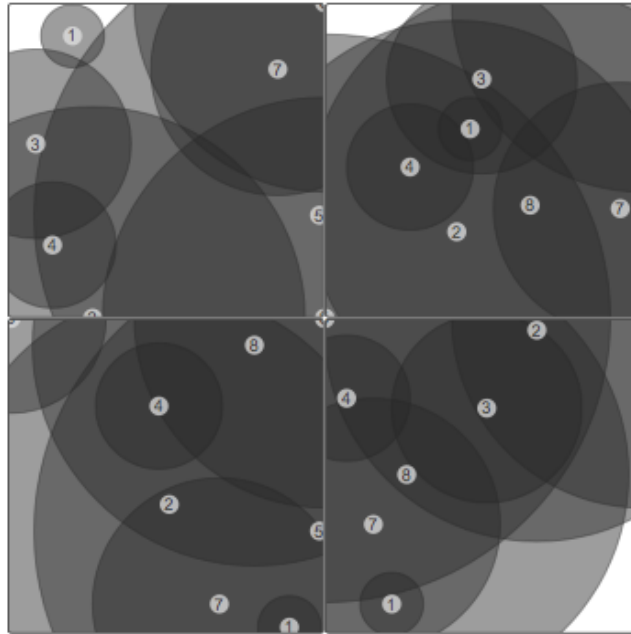


Fig. 28. The Qu4rters GUI.

These nodes take the input of the user and report an interpolated value, from 1 at their centre to 0 at their outside edge. Each node has a different 2-D position and size, and may overlap others, thereby creating a complex interpolation space similar to those of Ross Bencina (2005) and Ali Momeni (2005). Before they can be navigated with any degree of purpose the arrangements of nodes must be learned and internalised by the performer. Given their considerable complexity, it may be useful for novices to explore one zone at a time before attempting to manipulate all four together.

## User Study

In order to supplement my own experiences, a small-scale user study was carried out in order to test and evaluate the instrument and its topographies. For reasons of consistency, the study closely followed the design detailed in Chapter 3. Seven people took part; three female and four male, aged from 25 to 53 years (average 38 years). Only one participant was a complete beginner (i.e. only a few months of

previous musical experience), but the remaining participants had between six months and five years of experience only (i.e. there were no truly experienced musicians).

When questioned about their experiences with the instrument, the majority of participants' accounts were neutral or ambivalent. The responses to some questions were slightly more pronounced than others (e.g. participants typically did not like the sound of the instrument), but overall the margins of opinion are too small to be conclusive. I will therefore not dwell on this statistical data here. More useful are the comments of participants. For example, one participant commented that:

Some features were impenetrable. I would sometimes make some interesting sounds, but then not be able to find them again.

There is thus some evidence that at least one participant was not able to mine the more sophisticated and features of the instrument.<sup>61</sup> This may explain why the instrument did not sufficiently "hook" this participant during this initial period of engagement. Another issue relates to the physical form of the table itself:

The table seems too big for live use; it would be awkward to transport. [...]  
It is quite a stretch to reach the far side, especially when seated.

This comment in particular directly influenced the desire to develop the iPad Topographies (i.e. more immediately accessible designs on a more mobile platform). These results will now be supplemented with a series of more personal and informal reflections.

## **Reflection and Discussion**

With the Drift topography, similar styles of performer-instrument interaction could be

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<sup>61</sup> Note that this is the least musically experienced group of any of the user studies.

seen to emerge across participants. Participants would typically first capture a sound, then try to make it change as quickly as possible, before pausing to listen carefully to the results while the loops repeated. Indeed, it was not uncommon for there to be stretches of little or no interaction at all. While this may seem strange to those versed in traditional musical instruments, with physical demands reduced, there would appear to be increased opportunity for the performer to take a step back and focus on the sound of the instrument. Interestingly, my own approach to the topography (developed prior to the user study and not revealed to study participants) was very similar. However, I would not only consider the instrument and the performer-instrument interaction, but also the acoustic environment, and try to curate a coherent palette of sound sources.

By comparison, the Qu4rters topography offers a more dense wall of sound, with far less definition between individual sound events. It may therefore be more difficult, at least initially, for the user to grasp the effect of their actions and the scope or their role. Also, unless multiple parameters are actively and simultaneously manipulated by the performer, its output can be rather placid and inert. One productive strategy is to involve both hands; the left to slowly circle one half of the screen, while the fingers of the right tap out patterns in the other half of the screen.

The Multi topography is quite similar to Qu4rters in terms of how it is played and the sounds it can produce. However, it is arguably a more difficult topography to play in that interactions have cumulative effect, and therefore the same gesture may result in a quite different outcome each time. All the same, there are signs that the Multi topography is able to support personal expression. For example, while one participant actively rendered and manipulated dense clouds of sound (see DVD example: mTable: User Study: chapter 4), another participant first set imagined grooves in motion, then stood back to listen as they played out and evolved over time (see DVD example: mTable: User Study: chapter 1). The latter is similar to my own approach to the topography. As with the Drift topography, this would typically involve a search for an enjoyable base sound, followed by only fine and occasional

subsequent adjustments to pitch and timbre. This sound would be sustained until it had exhausted its ability to hold the ear, at which point the search for a new sound would start over, thereby creating a kind of glacially-slow harmonic movement.

If the Drift, Qu4rters, and Multi topographies are quite closely related and can reasonably be considered a continuum of designs, the Anti topography is quite radically different and perhaps not directly comparable. While the performer is offered quite direct (if non-linear) control, the output of the Anti topography is primarily rhythmic, with much less emphasis on producing the sustained, heavily textured drones found in the other topographies. Overall, the Anti topography offers a significantly more abstract, but also less controllable and ultimately perhaps less successful experience than the other mTable topographies.

Despite their differences, a consistent theme across all of the topographies was that participants would first try to map out the finger positions needed to play an arbitrary but familiar motif, then try to repeat it from memory. It may therefore be best to avoid topographies that evolve or change over time. I found it particularly curious that some participants persisted with this approach even when the topography actively resisted conventional musical rudiments. Nevertheless, after the initial period of familiarisation, more notable differences in approach between performers (i.e. expressive variation) start to emerge. For Jordà (2005), these differences offer an indication of the flexibility of an instrument. He argues that flexibility is important, for an instrument must be able to produce a range of music; both good and bad (however these are defined), if it is to be more than a short-lived toy.

## **Summary**

Informed by the framework set out in the previous chapter, the mTable topographies have explored a range of approaches to multi-touch musical interaction. These range from four directly controlled real-time samplers to a quartet of indirectly controlled

generative musical instruments. While imperfect and perhaps only sporadically successful, the results are encouraging enough for me to continue to develop this work and its ideas further.

## **iPad Topographies**

If the physical demands of the mTable (in terms of transport, setup time and storage) may not be unreasonable (they are comparable to those made by an acoustic drum kit), they were substantial enough for the more portable tablet form of the Apple iPad to hold instant appeal. Crucially, while the surface area of the iPad screen is much smaller than that of the mTable surface, it appeared large enough to be useful, without the finger/screen occlusion issues that hinder user interaction on the iPhone and iPod Touch platforms. Beginning work on the new platform, the decision was made to keep the essence of the mTable topographies intact, yet try to make improvements to their accessibility, robustness, and flexibility.

## **System Design**

Unlike the home-made mTable, the iPad is obviously off-the-shelf, unmodified hardware. Thus, this section on the design of the system (see Fig. 29) will be comparatively brief. The initial idea was to develop Pd patches that would run natively on the iPad using the RjDj application (Reality Jockey Ltd., 2010), but it was soon decided to shift the most computationally-expensive aspects to a separate computer to enable more sophisticated synthesis techniques to be used.



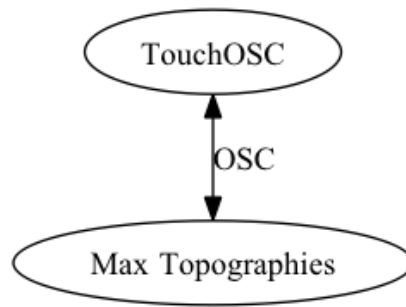


Fig. 29. The generic iPad system.

The TouchOSC and C74 applications (Hexler, 2010; van Veen and Douma, 2010) were selected for the iPad end, thereby enabling the creation of sophisticated Graphical User Interfaces (GUIs). These communicate with a laptop running Max software using the OSC protocol.

## Topographies

Of the five topographies developed for the iPad, three (Drone, Contra 2, and Qu4rters) are directly descended from the mTable topographies, while the other two (Brenschluss and Androids) are completely new developments.

### Drone

The Drone topography takes the Multi topography for the mTable as its starting point, then pares it back to a single oscillator fed into a variable delay line based on the *[+pitchdelay~]* external by Erbe (2010). The oscillator features three different waveform types (sine, saw, and square), while the output of the delay line is able to be modulated in three different ways; direct out (bypass), self-amplitude modulation (AM), and self-frequency modulation (FM). Thus, despite its economical means, the

Drone topography is surprisingly flexible. Although its rhythmic possibilities are limited, it is able to produce a wide variety of timbres and tones, from wiry feedback and metallic scraping, to ambient dronescapes and drifting tones.

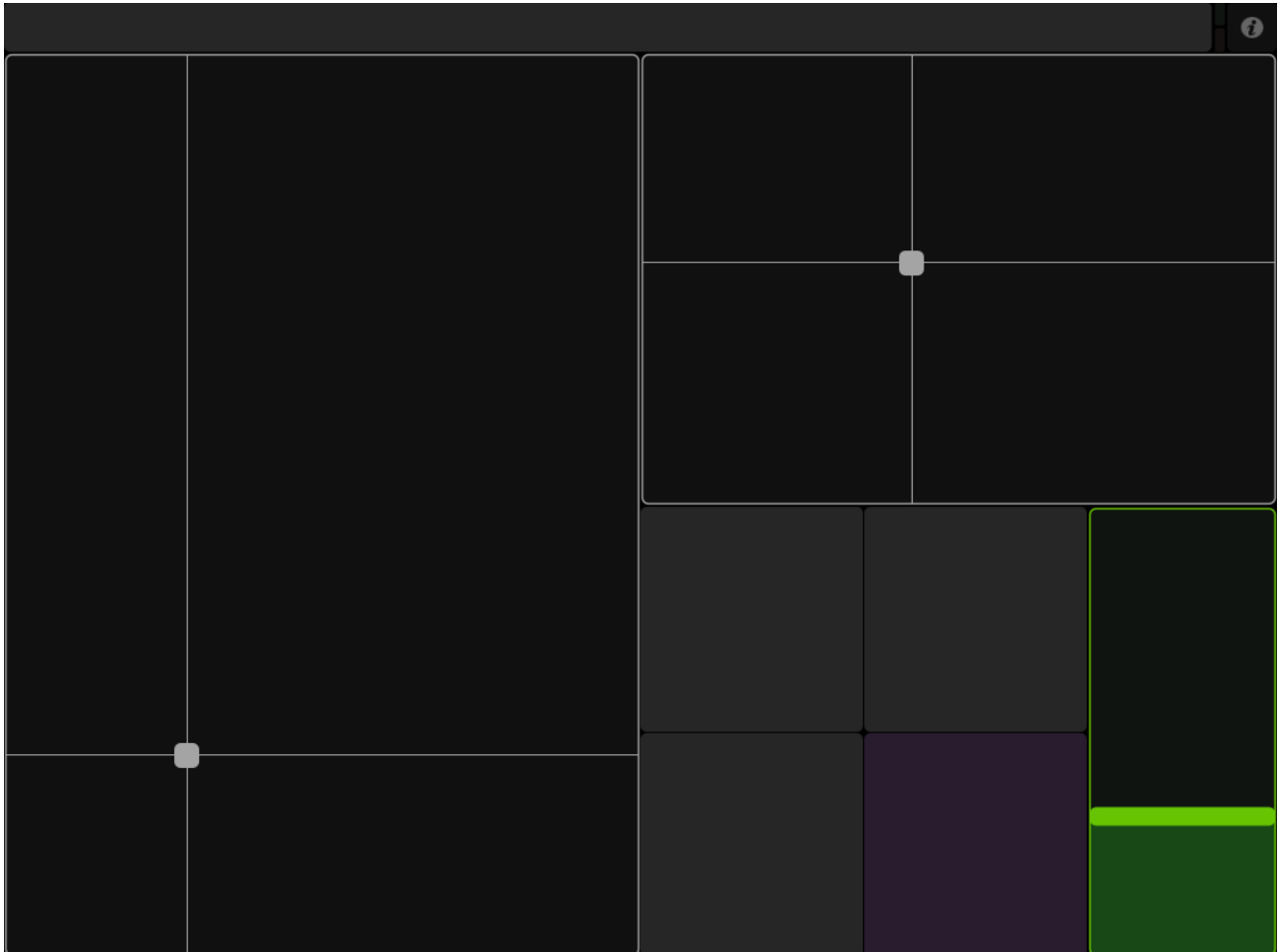


Fig. 30. The Drone iPad GUI.

The Drone GUI consists of two XY pads, one large and one small, four push-buttons, and a vertical slider (see Fig. 30). Pitch is mapped to the vertical axes of both XY pads. These usually offer discrete and continuous control respectively, but in AM and FM modes the large pad controls the frequency of the carrier and the small pad the frequency of the modulator. The X (horizontal) axes meanwhile are mapped to loop/modulation depth (large pad) and the amount of feedback (small pad).

Depending on mode, the vertical slider either sets the pitch interval between the dry and delayed sound (see Fig. 31), from unison to one octave difference (see below), or

sets the modulation ratio, from 16:1 to 1:16. The push buttons enable the performer to jump between octaves (from two octaves down to one octave up), and to choose between direct, AM, and FM modes.



Fig. 31. The Drone patch played by a user study participant. The pitch interval control can be seen under the right index finger.

In contrast to the Brenschluss topography (see below), it is apparent that the Drone topography requires more continuous stimulation in order to produce sound (see DVD example: iPad Topographies: User Study: chapter 4). Nevertheless, it is notable that these demands (in terms of performer-instrument interaction) are still considerably less intensive than those made by acoustic instruments.

## Contra 2

The Contra 2 topography is based on the Anti topography for the mTable, but while the premise and basic character of its predecessor are maintained, there are a number of important differences. Most notably, the performance interface has been completely redesigned for the iPad screen, and the parameters of the Max patch have been refined to improve their durability and musical flexibility.

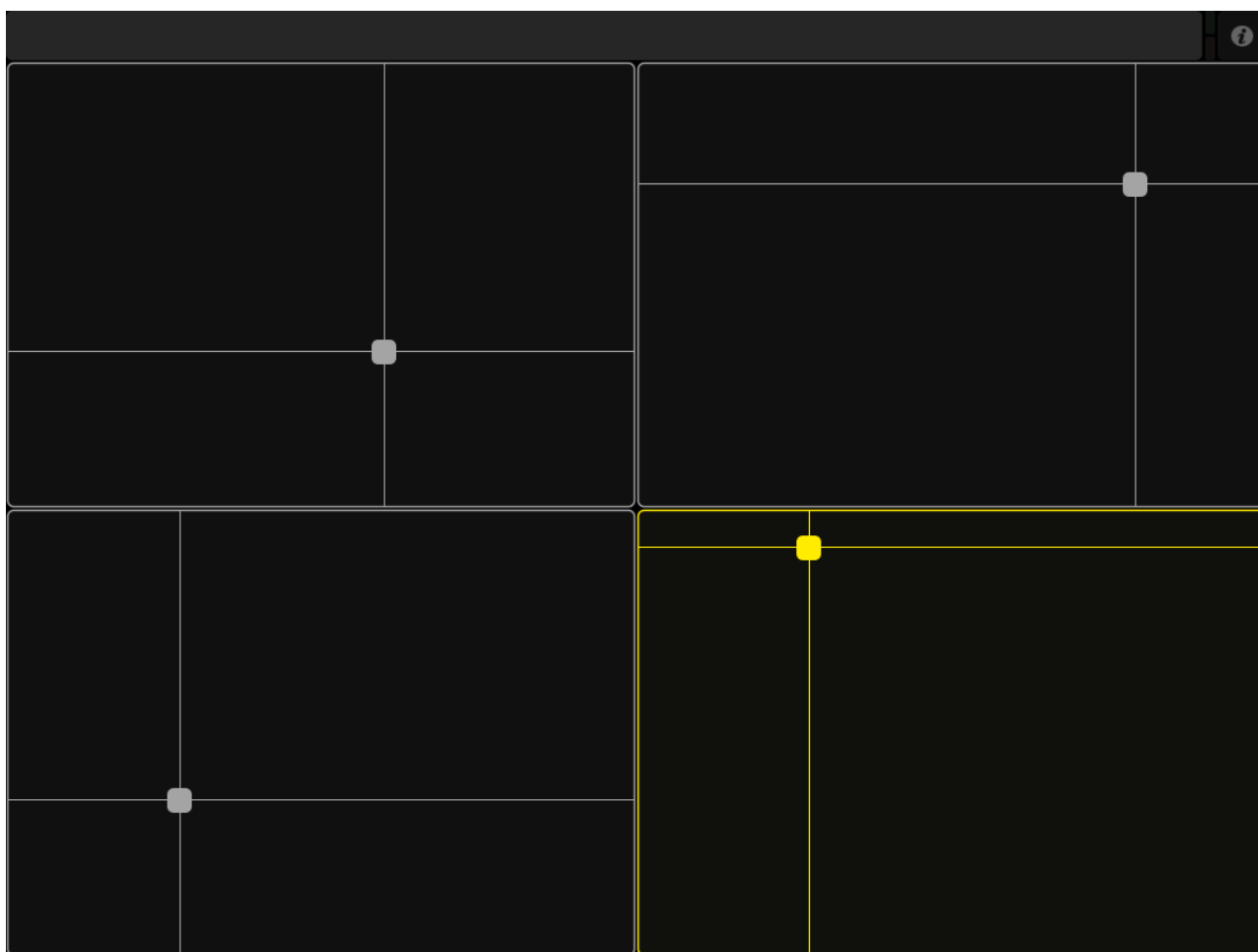


Fig. 32. The Contra 2 iPad GUI.

As with its mTable predecessor, the Contra 2 GUI offers the performer only indirect control over the Pd patch. The outputs of two equally sized XY pads (see Fig. 32) are scaled to the upper bounds and maximum step size of random 1-D walks. These in turn control the parameters of a combined audio-rate

sequencer/synthesiser/granulator. While there are relatively few periods of (unwanted) silence, this system remains extremely sensitive to small parameter changes. Thus, if the Drone topography could be described as smoothly continuous, the Contra 2 topography (like the Anti topography before it) is comparatively twitchy, unstable, and decidedly non-linear.

## **Brenschluss**

The white line, abruptly, has stopped its climb. That would be fuel cutoff, end of burning, what's their word...Brenschluss. We don't have one. Or else it's classified. (Pynchon, 1973, p. 6)



Fig. 33. The Brenschluss topography played by a user study participant.

As can be seen on the portfolio DVD (see DVD example: iPad Topographies: User Study: chapter 2), the Brenschluss topography responds to interaction in two zones. As with the Multi topography for the mTable, these zones are allocated to the left and

right halves of the multi-touch surface (shown above). The left zone (yellow) sets the upper bounds of stochastically-determined frequency and duration parameters, while the right zone (purple) determines the number of oscillators that are active simultaneously (from 8 to 128), and the parameters of a stereo reverb effect.

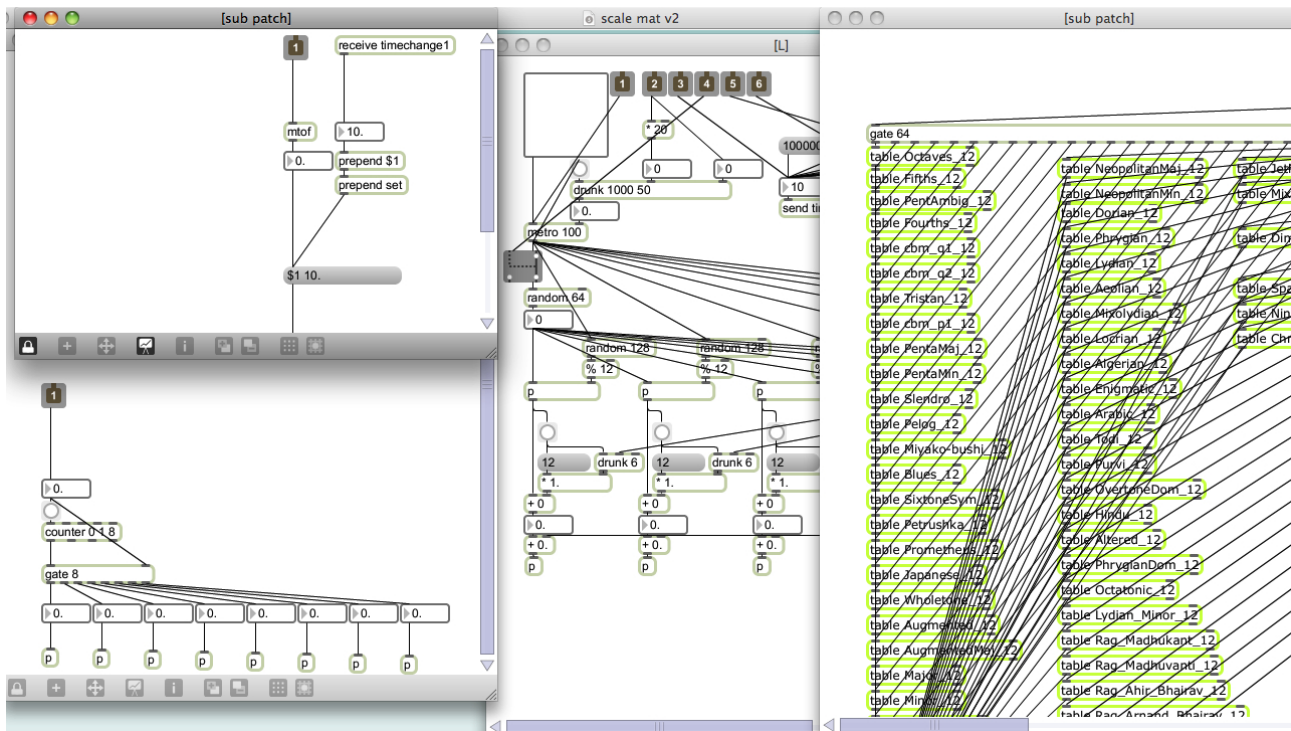


Fig. 34. Various Max sub-patches related to mapping and pitch sieving (based on Muir, 2010).

As with the Contra 2 topography, the performer does not have direct or fine control, but is instead able to collectively steer the proceedings at a higher level. Inspired by the titular term for the trajectory of a rocket after the fuel cuts off, sounds first arc upwards in frequency towards the defined limit, then glide back towards a baseline of 0Hz. Based on a design by Chris Muir (2010), a pitch sieve is used to quantise these sounds to one of 46 randomly determined pitch scales (see Fig. 34). Although each individual sound is a simple sine wave, so many sound events can occur simultaneously that additional harmonic complexity often occurs as a result of constructive and destructive interference.

Although the performer-instrument interaction is not as sparse as in the Drift topography for the mTable, Brenschluss is still a relatively "hands-off" topography in

that once the performer has found a palatable sound, the topography can be left to drift of its own accord. The performer may potentially not manipulate the screen again until they wish to substantially alter the musical output.

## Qu4rters 2

As its name implies, Qu4rters 2 is derived from the Qu4rters topography for the mTable. Like its predecessor, four generative musical instruments are able to be collectively and loosely steered, rather than directly or finely controlled by the performer.



Fig. 35. The Qu4rters 2 GUI.

The iPad GUI for this topography features two XY pads and five push buttons (see Fig. 35). The left XY pad determines the harmonic and rhythmic relationships (expressed as ratios) between the four instruments, while the right XY pad controls the maximum step size and the wet/dry ratio of a reverb effect. The push buttons enable each instrument to be muted individually (grey), or all of the instruments to be muted simultaneously (green).

## **Androids**

Androids is a new topography created specifically for the iPad platform. Similar to the ServoString instrument presented later in this chapter, it is inspired by the possibility of plasticity (i.e. reconfigurability) in neural networks, as well as (more generally) the potential for computer programs to produce radically different outcomes each time they run (Collins, 2006). At the heart of the topography is an 8x8 matrix of nodes that perform the role of pseudo-neurons (see below). The connections between the nodes, randomly spawned when the Max patch is opened, are able to be opened or closed by the performer, thereby influencing the level of musical activity.



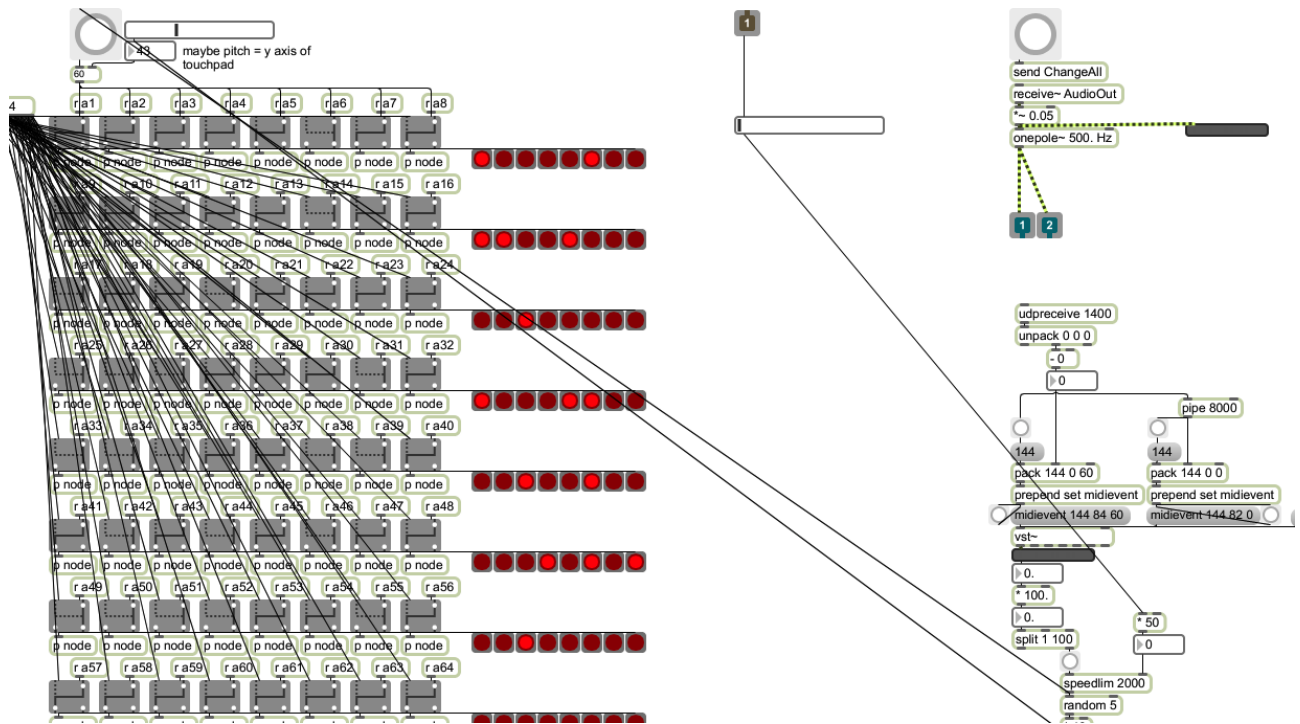


Fig. 36. The Androids Max patch (top level) showing the arrangement of pseudo-neurons.

Perhaps the most distinctive feature of the Androids topography is its performance interface (see Fig. 37). This consists of 64 procedurally-generated toggle switches created with the C74 iPad app and Max external (van Veen and Douma, 2010). Each toggle is mapped to a different node, which will open and close each time the toggle is pressed. However, the layout of the GUI is not static but changes each time the Max patch is reloaded, thereby actively resisting the learning of causal relationships. Thus, to play this topography (at least in any kind of semi-controlled manner) requires that the performer improvise, and respond to the instrument on a moment-by-moment basis.

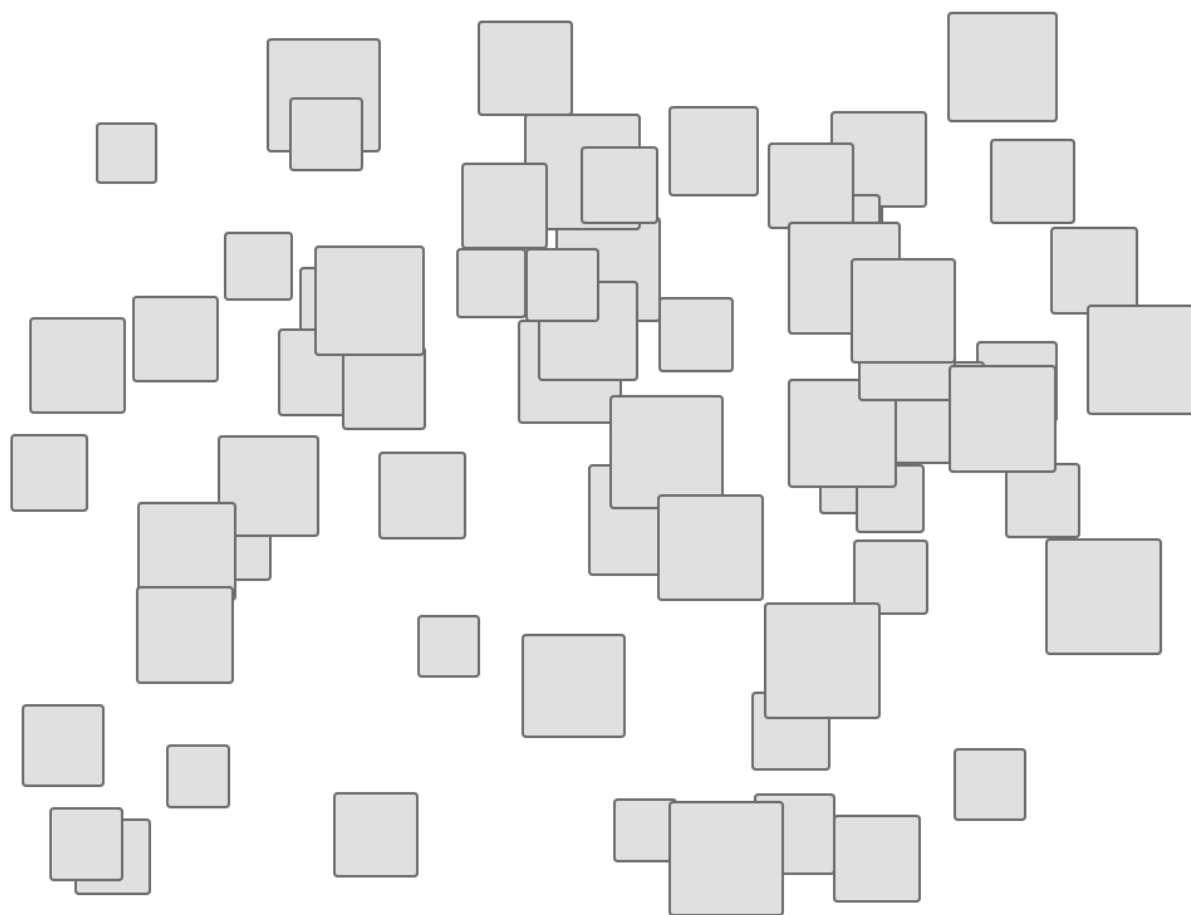


Fig. 37. The procedurally-generated Androids iPad GUI. The layout is different each time the instrument is played.

Within each node is a separate instance of the Karplus-Strong string algorithm (Karplus and Strong, 1983). The pitch of each string is chosen at random from a pre-composed list. Nodes are triggered whenever they receive a bang,<sup>62</sup> but are only able to receive bangs when open. Nodes can be triggered in one of two ways. First, the top row of eight nodes can be triggered by a global metronome. Second, all nodes can be triggered by the output of any other node to which they are connected. The performer is able to control both the speed of the global metronome and the delay time between nodes but the effect of adjusting these parameters is not always predictable. For example, as the metronome reaches faster rates the topography becomes particularly susceptible to runaway (i.e. unstoppable) chain reactions: the performer must carefully manage the number of active nodes if these are to be avoided.

<sup>62</sup> Max parlance for a trigger message.

## User Study

As with the mTable instrument (which informed these designs), a small-scale user study was carried out in order to evaluate the instrument and its topographies. This study again followed the basic design set out in the previous chapter. Eight participants took part, all male, and aged between 21 and 64 years (average 34 years). Two participants had little or no prior musical experience, five had a moderate amount of musical experience, and one was a very experienced musician (ten or more years of experience playing the piano). In addition to being observed and recorded, the OSC data generated by user interactions were also collected and stored so that comparative visualisations could subsequently be produced.

Participants rated the iPad Topographies slightly more favourably than the mTable group had rated their instrument in almost all of the areas polled. This may seem counter-intuitive given that these participants considered this instrument to be the most alien (i.e. least familiar) of any group, but they also considered it to err on the side of being easy to learn, and the rate of learning to be more rapid than slow (albeit both by small amounts). There was little consensus between participants as to intimate, direct, or flowing they considered their experience, so these aspects will not be further detailed. Instead, the interested reader is referred to Appendix C. However, while participants overall tended to consider the sound of the instrument to be only marginally more pleasant than unpleasant, and its musical possibilities only slightly more broad than narrow, the Drone topography received notably more positive responses. To this end, one participant commented that:

this gave me lots of new ideas.

However, another participant commented that:

I've never really played an instrument before - but always wanted to. I have an iPad though so perhaps I will start playing something like this.

Thus, for some participants at least, it may be the novelty of the iPad platform itself (i.e. the seductive appeal of a shiny and apparently new technology) rather than the specific musical topography that appeals. It would therefore be interesting to carry out the same study again in a few years time, when the initial novelty of the technology is likely to have faded.

## **Further Results**

To enable further discussion, visualisations created from the OSC data captured during the sessions will now be presented. These represent four different participants playing three different topographies as seen in Figs. 38-41:



Fig. 38. User 4 Drone topography – pattern of surface interaction at end of session. Thicker lines represent faster movements from one position to another.



Fig. 39. User 7 Drone topography – pattern of surface interaction at end of session. Thicker lines represent faster movements from one position to another.



Fig. 40. User 3 Androids topography – pattern of surface interaction at end of session. Thicker lines represent faster movements from one position to another.



Fig. 41. User 8 Qu4rters 2 topography – pattern of surface interaction at end of session. Thicker lines represent faster movements from one position to another.

Although users 4 (see Fig. 38) and 7 (see Fig. 39) both play the Drone topography, they have contrasting styles of interaction. The interaction style of user 4, for example, is quite economical, but he tends to manipulate the instrument with broad, angular gestures (see DVD example: iPad Topographies: User Study: chapter 1). The user interaction is largely constrained to the edges of the screen and quite evenly split from left to right, suggesting that both hands are used approximately equally. By comparison the interaction style of user 7 (see DVD example: iPad Topographies: User Study: chapter 4) is much more active. The dense field of squirrely lines perhaps suggest a nervous energy. Both hands are again used, but this time the right hand dominates the left.

In contrast to users 4 and 7, who focussed their interactions around the edge of the screen, the interactions of user 3 with the Androids topography (see Fig. 40) form a three-spoked clump, while the interactions of user 8 and the Qu4rters 2 topography



(see Fig. 41) are focussed in a central ring. Thus, there would seem to be evidence of the interaction being shaped by the respective topographical affordances, as well as there being expressive differences between individual users. However, the patterns of interaction do not obviously correspond to the layout of the topographies, limiting the potential for quantitative assessment of accuracy, speed, and efficiency.

## **Reflection and Discussion**

If the iPad Topographies were generally more favourably received than their mTable predecessors, the newer topographies are certainly not equally successful. Take the Drone topography for example. This succeeds because it is quite simple to understand and play, yet also offers enough flexibility to maintain the interest of the performer over longer periods of time. From a personal perspective, I also found this topography to be the most consistently playable and capable of expressive subtlety.

This can be contrasted with the Androids topography. While the performer-instrument interaction is extremely direct (there is a one-to-one mapping between input gesture and outcome), the results of an action are unpredictable. Depending on the configuration generated, opening a single gate may have no effect at all, or a huge, cumulative effect on the rest of the topography and the output of the instrument. This makes the topography difficult to play, and – combined with the shifting nature of its GUI – nearly impossible to learn. While an interesting experiment, the longer-term appeal of the Androids topography may therefore be limited, for any progress in the abilities of the performer is rendered largely redundant at the end of each session, and they must essentially start anew each time.

At this point it is pertinent to note that comparing the iPad Topographies to the earlier mTable work raises the issue of platform specificity. For instance, the portability of the iPad enables it to be used in places and situations that are not accessible to the mTable. However, it must be remembered that the iPad is not a

dedicated musical device, and must typically also browse the Web, deliver presentations, play games, and share media (etc.). It could therefore reasonably be argued that the table and tablet formats are not be directly comparable.

## Summary

The iPad Topographies have expanded and refined the ideas present in the mTable. They represent a concerted attempt to address issues of accessibility and portability that to some extent undermined the earlier multi-touch work. The Drone topography elicited a particularly positive response, concurring with my own experiences as its designer-performer. It can be therefore seen to exemplify aspirational instrumental qualities such as expressiveness, directness and intimacy beyond the acoustic paradigm, and the potential for long-term engagement (see Chapter 2).

## ServoString

An assemblage of the detritus created by digital culture's endless cycle of upgrades and planned obsolescence (Fino-Radin, 2010),<sup>63</sup> the ServoString is a robotic string instrument formed from a network of hardware, software, and electro-mechanical elements. While the result of cohesive design, its fragmented appearance is far removed from the object-like forms of traditional instruments. Conceptually, the ServoString design is inspired by mathematical models of neurons exchanging spiking signals (Gelenbe, 1990). It can therefore be related to the *Connection Machine*, a massively parallel computer with a 12-dimensional network of processors (Hillis, 1985, pp. 18–22), the synthesiser created by Forrest Warthman and Tudor for

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<sup>63</sup> The first version of the instrument was cobbled together entirely from hacked junk hardware - motors from discarded CD players, a servo from a toy remote controlled car, etc.

the piece *Neural Synthesis Plus* (Warthman, 1995), and the Androids topography for the iPad presented earlier in this chapter. The most immediate antecedents are perhaps the SuperString (Gehlhaar, 1971), a simple electric instrument comprised of two strings stretched over a length of wood and amplified by a magnetic pickup, and the robotic instruments offered by the likes of Scott Wilson (2002, p. 431) and Xiaoyang Feng (2010).

## System Design

The ServoString instrument evolved from a sketch created in Max, whereby twelve virtual strings were implemented based on the Karplus-Strong algorithm. These were able to be collectively controlled by hand movements, surveyed by two webcams (one for each hand). This design evolved considerably over time. In its most recent form, the ServoString instrument consists of three main elements (see Fig. 42):

- an Arduino-based controller offering four DoF;
- a laptop running a Max patch;
- six sound generation units, each consisting of a pair of metal strings stretched between two fixed bridges, plucked by a servo.

The controller incorporates a rubberised stretch sensor, two IR rangefinders, and a pressure sensitive resistive strip. This arrangement offers the performer four DoF, although only two provide any passive haptic feedback. Based on the Arduino microcontroller, the controller uses the Maxuino firmware to communicate with the Max patch over USB. Similar to the Androids topography, the Max patch implements a simple neural network model that maps controller input to the starting and stopping of generative processes that act on the string units. The nature of the control is therefore strictly indirect, instead offering the performer the ability to loosely steer

the instrument.

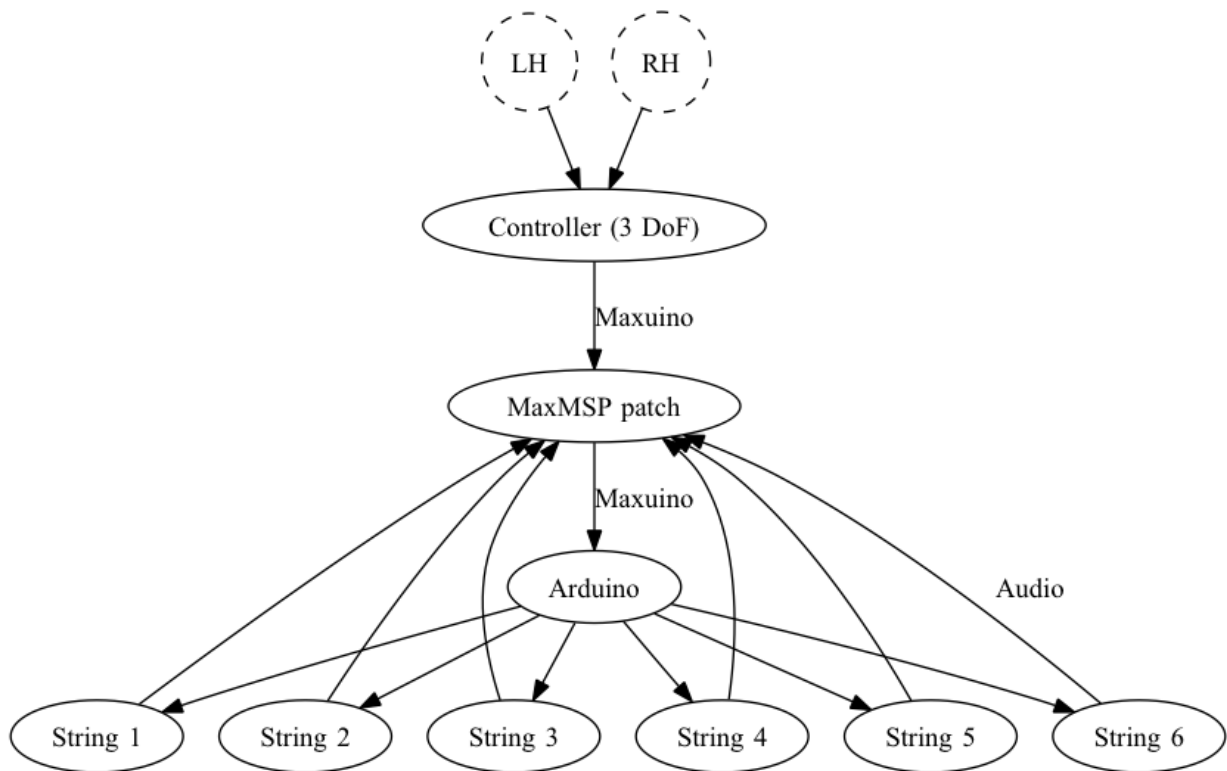


Fig. 42. Diagram of the ServoString system.

The design of the string units is based on the aforementioned ServoString instrument. In this instance, six units are implemented. This leads, in chromatic tuning, to a range of one octave. In each unit, two pairs of machine heads hold two steel strings at tension over fixed bridges; one at each end of the unit. A magnetic guitar-style pickup is attached near the base of the unit in order to amplify the sound, while a servo is positioned between the two strings. The servo can pluck either string up to five times per second, but not both simultaneously. Like the controller, each servo is interfaced with an Arduino microcontroller, and is able to be controlled from within Max using the Maxuino firmware.



Fig. 43. The servo-based plucking mechanism of the ServoString instrument.

In addition to servo control, the Max patch mixes the amplified sound of the instrument and processes the summed signals. A light distortion/overdrive and reverb effect are applied before the sound diffusion stage.





Fig. 44. The ServoString instrument in use.

While the version of the ServoString primarily developed by Gehlhaar was developed for use in workshops for disabled people (see Fig. 44), the version presented here (with its more complex, neural net-inspired mappings), was intended as a personal performance instrument (i.e. an instrument I would perform with myself). Thus, while others have on occasion played the instrument, it is evaluated here through a process of self-reflection rather than the user studies adopted elsewhere in this chapter. To aid this self-reflective process a journal/notebook was kept and recordings made. These provide the foundation for the subsequent discursive section.

## Reflection and Discussion

If it is often the aim of the designer to minimise unpredictability in search of ease of use, learnability, and the possibility of mastery, the ServoString case is different in that it is a personal performance instrument. Thus, with ease of use much less of an issue (I was prepared to persevere), unpredictability was emphasised throughout the instrument design, most notably in its mappings and musical algorithms. While

similar to other portfolio instruments in that it is able to be indirectly steered rather than directly controlled, the ServoString is considerably more unruly, to the extent it can appear to have a will of its own. At times the performer is simply taken for a ride (i.e. it operates largely autonomously), and must try to hold on until the instrument becomes more amiable. While I found this power-shift to be liberating, it may be that other users would not be so inclined to accept the demands of this fundamentally non-traditional performer-instrument relationship.

What makes the ServoString particularly difficult to play, at least initially, is that cause and effect is not immediately obvious, and there is little haptic or visual feedback to indicate the present state of the instrument to the performer. Nevertheless, if the instrument offers few initial clues as to how its rangefinder inputs should be approached, a range of nuanced responses to different styles of interaction are slowly revealed over time. For example, an excessively active state can be calmed by holding both hands still above the rangefinders for a few seconds. If this position is maintained further, the musical output of the instrument will stop completely. Conversely, rapidly moving the hands above the rangefinders will awaken the instrument from a slumber. The effect is particularly pronounced if the movements are out of phase (i.e. as one hand moves upwards the other moves in the opposite direction).

The performance techniques used combined with the amassed elements of the instrument itself lend the ServoString a substantial and prominent visual aspect. This is quite different to the dematerialised nature of many digital instruments, and to some extent recalls my earlier electro-mechanical sound installations such as Loop (see DVD example: Early Work: Loop). As with traditional (acoustic) instruments, the means of sound production is made clear to and readable by audiences both in terms of its codes and scale.<sup>64</sup> In this respect it is similar to (but considerably more successful than) the Rewire topography for the Scanners instrument. This is not to suggest that all digital instruments should be robotic, for they are limited in terms of

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<sup>64</sup> i.e. it is clear that sound is produced by the interaction of physical materials.

speed, accuracy, and wear in ways that do not significantly affect instruments realised entirely in software. Nevertheless, in the present era of the long tail (Anderson, 2006, p. 1–9)<sup>65</sup> there is surely a place for such systems, however niche. Indeed, it could be suggested that the diversity of instruments and the contrast this provides make a significant contribution to the richness of the field.<sup>66</sup> Maintaining this variety is important if digital musical instruments are to avoid the homogenising effect of the keyboard that beset both analogue and MIDI synthesisers, and had significant effect on subsequent music technologies and production (see Chapter 2).

## Summary

The ServoString is a more personal instrument, and thus is subject to fewer demands in terms of accessibility and ease of use. Indeed, its instabilities and unpredictabilities are actively emphasised. While this initially makes the ServoString very difficult to pick up and play, a range of nuanced responses to performer input start to emerge over time.

## Vanishing Point

The Vanishing Point instrument (see DVD example: Vanishing Point: Vanishing Point Overview) has its roots in the earlier (and collaborative) Physical Sequencer instrument. In particular, that instrument's unenviable combination of heavy, monolithic physical form and fragile electronics prompted the thought of a new instrument that would be more economical and robust, yet still able to survey the entire upper body of the performer. I also wanted to break from the rigidly quantised

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<sup>65</sup> i.e. an era of many niches that are able to exist below the mainstream.

<sup>66</sup> i.e. it is not the aim of this research to make the digital musical instruments field less diverse, but to develop strategies that help these instruments to be better designed.



4/4 grid imposed by the Physical Sequencer and return to the more pliable and fluid granular synthesis techniques (Roads, 2001) of my Footfall installation (2006) (see DVD example: Early Work: Footfall).

Aware that its possibilities had expanded since its dismissal as clerical and inexpressive in the early 2000s (Stuart, 2003), I turned first to the integral interface of my laptop computer. Like many contemporary laptops, the Apple (2010) MacBook Pro features multiple inbuilt sensors that offer functionality far beyond that of the traditional keyboard and trackpad (Fiebrink, Wang and Cook, 2007), yet have little (if any) impact on portability. After a period of initial exploration and experimentation, its iSight camera was settled upon as a potentially productive basis for performer-instrument interaction.

## System Design

As the hardware used is simply that built into the MacBook Pro laptop, the focus of this section is on software. At the core of the instrument are two patches, one for video, the other audio.<sup>67</sup> The two communicate over OSC.

The video patch first grabs the output of the iSight camera (800x600 pixels at 30fps), then applies slit-scan processing to the incoming video stream (see Fig. 45). Based on the implementation of Barry Threw (2008), this is an update of the historical (mechanical) photographic technique (Levin, 2010). This transforms the performer-image relationship from one of direct representation or mirroring into one that is much more playful. Within this mediated plane, the body becomes fluidly malleable, and the performer is able to distort their image in unusually expressive (and sometimes very funny) ways (see DVD example: Vanishing Point: Interface).

The results of these experimental works exploring and shifting the

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<sup>67</sup> The two are kept separate to allow the patches to be run on different machines if necessary.

parameters of the linear film are often oddly abstract and quite expressive in their formal composition, and, consciously elude simple legibility. (Jaschko, 2002)

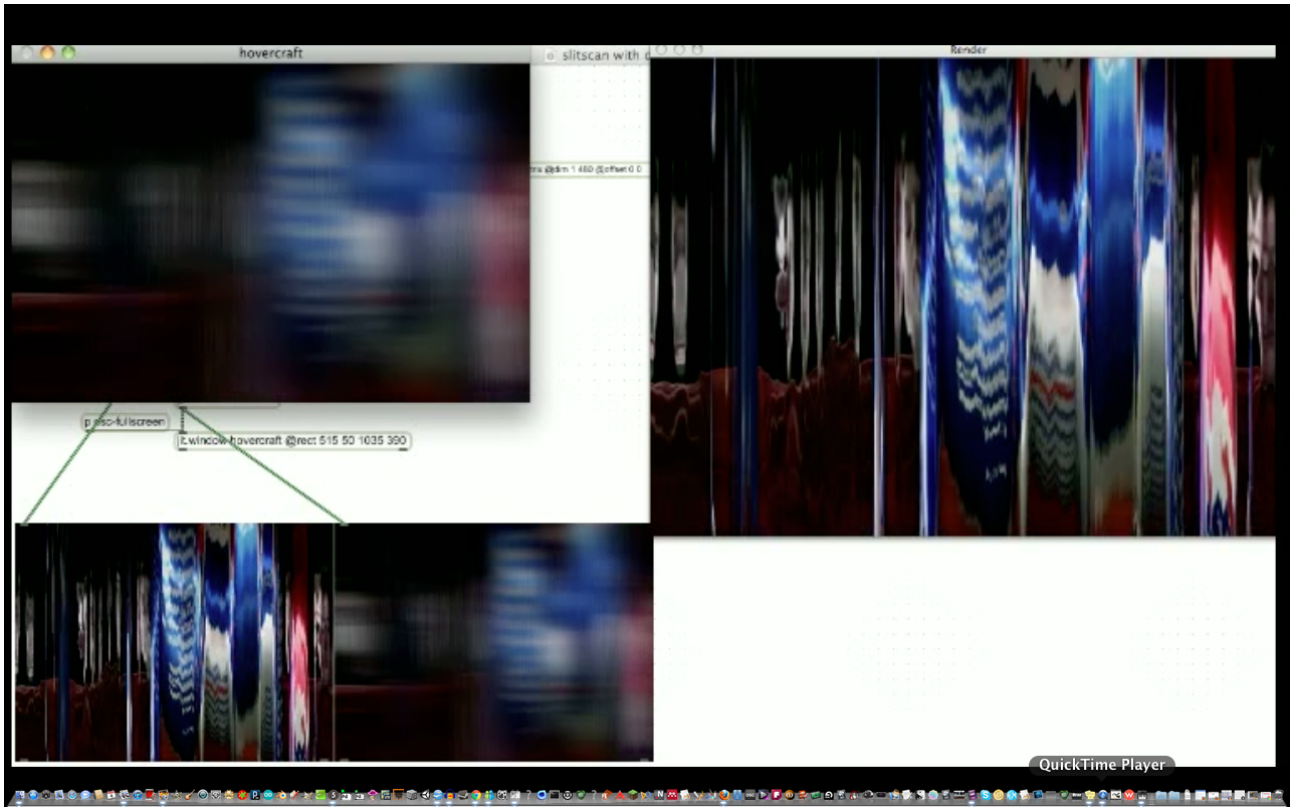


Fig. 45. The slit-scan interface.

As the slit-scan output scrolls from right to left, the amount of change (i.e. movement) per frame is calculated, and compared to the amount of movement in the two most recent frames of the unprocessed video feed. In other words, the present actions of the performer are compared to a distorted echo of their previous selves (a delay of a few seconds by default). This generates three variables:

- current activity (0-127)
- slit-scan activity (0-127)
- difference (0-127)

These are collated into a bundle and sent over OSC into the audio patch at a rate of 30 bundles per second.

Within the audio patch (see Fig. 46), the three activity values steer a generative musical system that controls a hybrid synthesis/sample playback system whereby sounds are both synthesised in real-time and pulled from a pre-composed library of audio samples. The outputs of this system are first routed into an audio matrix to enable cross-modulation, then fed into a stereo granulator (Trueman and Dubois, 2001) and treated with a plate-style reverb effect.

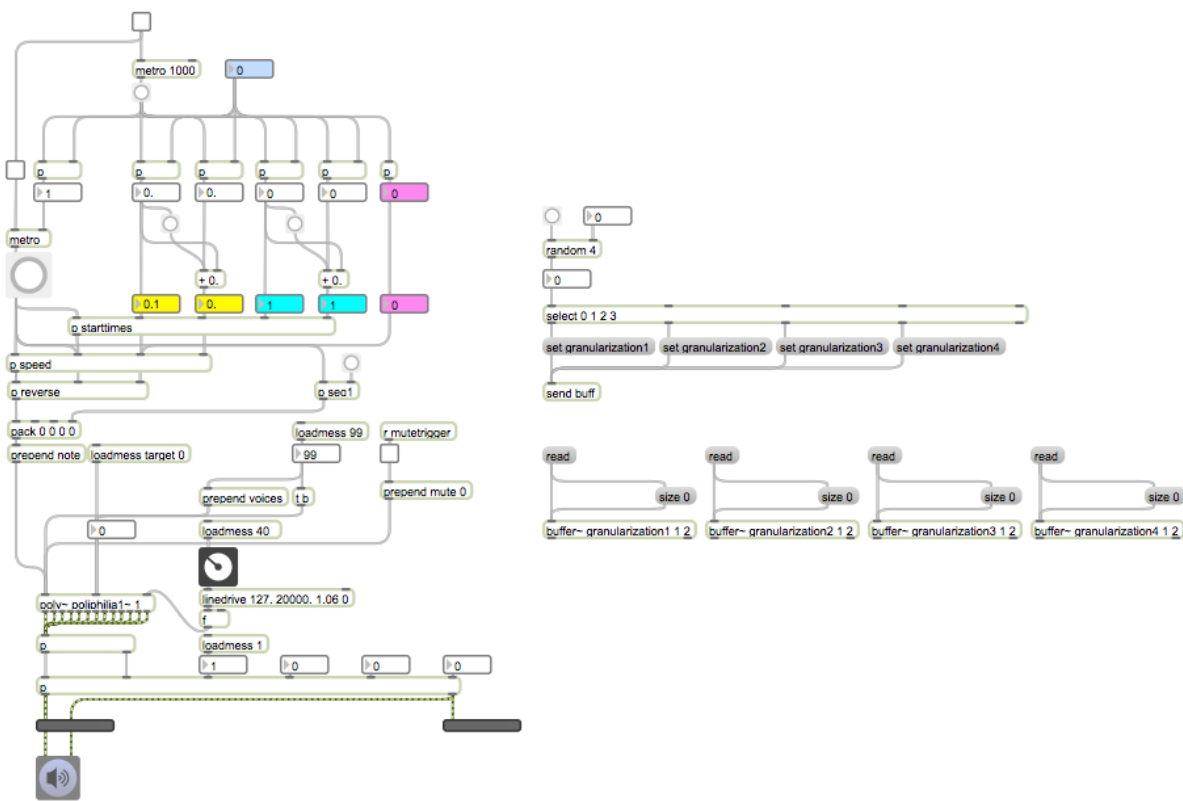


Fig. 46. The audio patch for the Vanishing Point instrument. Audio playback buffers can be seen to the right of the patch, while the stereo granulator be seen near the bottom of the patch.

Following a mirroring approach to mapping performance input to musical output, higher levels of activity generally cause the system to become more active. Similarly, larger differences between current and slit-scan activity levels increase the range and maximum step size of a series of 1-D random walks (see Fowler, 2007) connected to synthesis parameters. These include grain size, cloud density, dynamic balance, and

the harmonic relationships between oscillators. Although control is very indirect, like the Anti 2 topography for the iPad, relatively small changes can have a dramatic and cumulative effect on the behaviour of the instrument.

## User Study

As with the mTable and iPad Topographies instruments, a small-scale user study was carried out according to the basic design detailed in Chapter 3. Six people took part; five male and one female, aged from 19 to 55 years (average 35 years). Two participants were very experienced musicians (ten or more years of previous musical experience), three were moderately experienced (one to three years of previous musical experience), and one participant stated that they had no prior musical experience at all.

While participants tended to give slightly positive responses to more than half of the questions asked, and were notably enthusiastic about the capacity of the instrument to inspire, there was a mixed reception overall. For example, the comments of two participants were exceedingly positive:

Vanishing Point system was pretty wild at times but overall I greatly enjoyed myself.

Although I usually sing, it was cool to try something completely different.

However, another participant commented that:

I felt a bit silly and exposed at first, although I eventually began to enjoy myself.

Thus, for this participant at least, the instrument appears (at least initially) to have

spurred an acute sense of self-consciousness. This perhaps arises from a conflict between the conventions and expectations that have become established around musical instruments (and ours interactions with them) over centuries, and the "whole body" model of interaction offered by the Vanishing Point instrument.

## **Reflection and Discussion**

In contrast to the ServoString instrument, Vanishing Point is heavy on visual feedback. However, the abstract nature of the on-screen representation combined with the optical distortion of the video camera lens poses a problem of orientation, for to accurately translate 3-D movements onto a 2-D plane requires practice (see DVD example: Vanishing Point: Demonstration). Indeed, if the positions in the plane of different sonic processes can be memorised quite quickly, the ability to activate them repeatedly (even if their outcomes remain unpredictable), on demand, takes a substantial investment of time on the part of the performer.

Due to the frame rate of the video camera, the Vanishing Point system typically responds best to slow, precise gestures (see Fig. 47). If moderately fast movements will work adequately, very rapid movements usually appear only as indistinct flecks of light on screen, or are not picked up at all. Thus, a particular kind of rhythm is inevitably suggested. While the performer may depart from this groove, any substantial shift in tempo is not without difficulty, for the instrument will often provide stubborn resistance.



Fig. 47. The Vanishing Point instrument played by the author.

Another consequence of the unencumbered (i.e. hands off) and broadly gestural performer-instrument interaction is that, without the reassurance of a tangible instrumental object in the hands, the performer may feel unusually exposed and vulnerable. This relates to the comment of Jordà (2005), that not everyone is comfortable doing something that quite closely resembles dancing in front of an audience. In these circumstances, the instrument may actually hinder rather than encourage and enable participation; quite the opposite of its intended effect. From a personal perspective, the Nintendo Wii remote can be seen to offer a similar mismatch between the intention of the designer and the experience of the user. If conventional video game controllers pose few (if any) problems, the Nintendo Wii remote, while intended to broaden user appeal, imposes significant additional barriers to my participation. Whereas a conventional controller can be held in one hand and

then manipulated with both thumbs, the Wii remote and nunchuck attachment need to be grasped in both hands (a demand that I cannot meet). At times, the physical demands of the Vanishing Point instrument posed similar barriers to participation. Unable to stand for extended periods and generally less mobile, I found myself essentially excluded from my own instrument, yet could still play conventional instruments such as the guitar and trumpet (albeit sitting down). Perhaps above all, these examples are useful reminders that the people who play digital musical instruments (and who will play them in future) are diverse, and there are likely to be few (if any) universal solutions.

The Vanishing Point instrument is also notable for its emphatic absence of tactile feedback. With sonic causality often blurred, it can be extremely difficult to determine the response of the instrument to each gestural input. This led to a tendency to exaggerate performance gestures in order to ensure that they would have palpable effect on the musical output. Although the two instruments are quite different in terms of mappings and sonic causality, this problem could perhaps have been better anticipated given the precedent set by the theremin, whereby a similar lack of haptic feedback makes accurate control of pitch fiendishly difficult.

Over time it became clear that the Vanishing Point instrument favoured the visual over the auditory sense to the extent that it was all too tempting to play the instrument based on the visual (screen-based) representation of the performer alone, with precious little consideration for the sounds produced. Thus, in an attempt to better engage with sound output of the instrument, I took part in an improvisation session with an electric guitarist. While the different textures of the instruments did not initially mesh, after two or three hours there was a definite sense of dialogue. That is, the guitarist had started to develop responses to the sounds made by the Vanishing Point instrument, while I had similarly started to coax (albeit a little unreliably) responses from the Vanishing Point instrument in relation to the guitar. Perhaps unsurprisingly I found this new musical context extremely challenging, but I was fascinated to hear that the guitarist not only felt similarly challenged, but also a

sense of satisfaction that he had managed to expand his sonic palette.

## **Summary**

The Vanishing Point instrument extends human-laptop interaction beyond the clerical scale to incorporate the whole body. At the heart of the system is a computer vision system that first surveys bodily movement, then applies a slit scan-style treatment to the captured images. This creates a distortion in the time domain that can be expressively manipulated by the performer. While these interactions are much slower than conventional performer-instrument interaction, they are also unusually playful. Nevertheless, the physicality of the interaction does not appeal to all, and for some may even pose a barrier to participation. What is more, the visual modality is emphasised to such an extent that it sometimes detracts from the musical output of the instrument.

## **DelayNet**

The DelayNet (see DVD example: DelayNet: DelayNet Overview) is an ambient, ephemeral, instrument: a series of interconnected but dematerialised structures that the performer can fill with sound. As with the earlier Drift topography for the mTable, these sounds are sourced in real-time from within the (localised) acoustic environment. Thus, the outputs of the instruments could be considered (heavily) processed field recordings in the manner of Christian Fennesz (2002). However, the DelayNet was initially inspired by the Aeolian Harp, an ancient Greek instrument in which the flow of wind past tensioned strings caused them to oscillate (Beyer, 1974). The DelayNet does not specifically imitate this arrangement, but its influence is



present in the use of the Karplus-Strong algorithm (Karplus and Strong, 1983; Roads, 1996, p. 263) to filter incoming audio.

## **System Design**

The DelayNet instrument consists of two main components:

- a gestural controller (an iPhone running the C74 application);
- a MaxMSP patch hosted on a laptop.

The controller transmits both accelerometer data and audio from its inbuilt microphone to the Max patch. The Max patch implements a multi-layered network of variable delay lines based on the Karplus-Strong string algorithm (Karplus and Strong, 1983; Roads, 1996, p. 263). When the controller is actively shaken or moved, a gate is opened and the microphone signal feeds into the first layer of delay lines. The amount of sound allowed into the network is determined by level of controller activity; more energetic movements allow more sound to enter. Once in this network, the microphone signal passes through three more layers of delay lines before reaching the audio output (see Fig. 48).

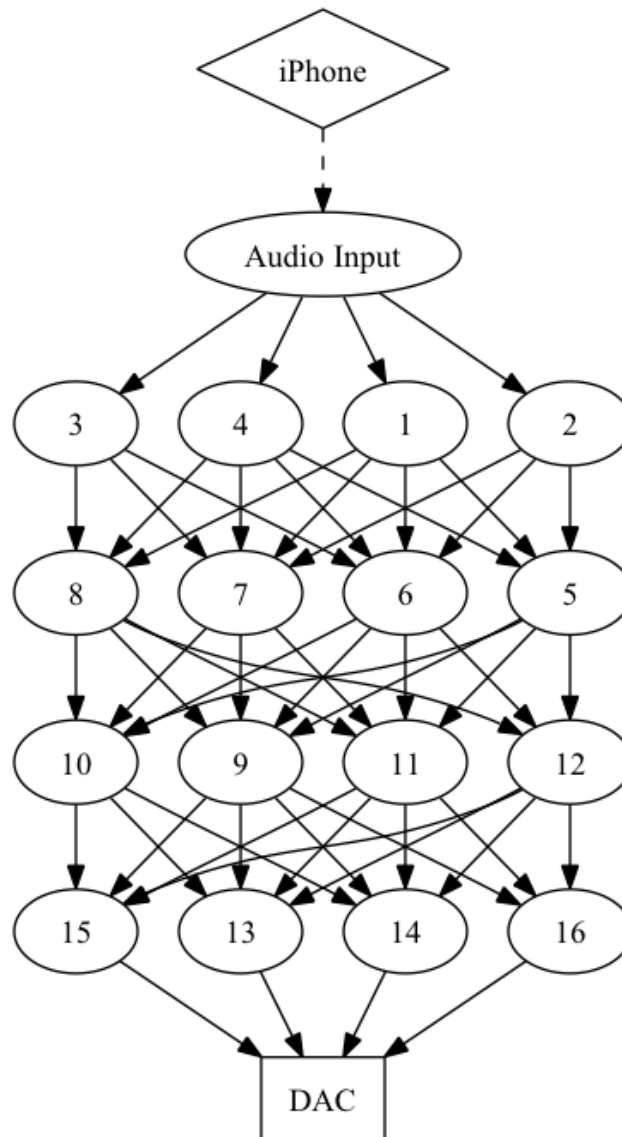


Fig. 48. System diagram for the DelayNet instrument.

The delay times of each layer are directly influenced by the pitch of the microphone signal. This is measured by a simple pitch detector (Puckette, 2008), the output of which is smoothed with a lowpass filter to minimise jitter. A small amount of random variation is then added so that outcomes are never entirely predictable, but higher pitched sounds from the microphone generally result in shorter delay times. The delay lines exert significant effect on the microphone signal, often transforming it to the point that its origin can often barely be recognised. Frequencies related to (i.e. multiples of) the pitch of the delay line will tend to be emphasised, while others will

be heavily attenuated. Progression through the layers of delay times is non-linear, and there are multiple feedback loops both within individual nodes and between layers (see Fig. 49). It can therefore take a considerable amount of time for a sound to pass through the system; latencies of 20 to 40 seconds are not uncommon. The final layer of delay lines differs from those that precede it in that it is directly connected to the main stereo audio output. Aside from compression, no further effects are added.

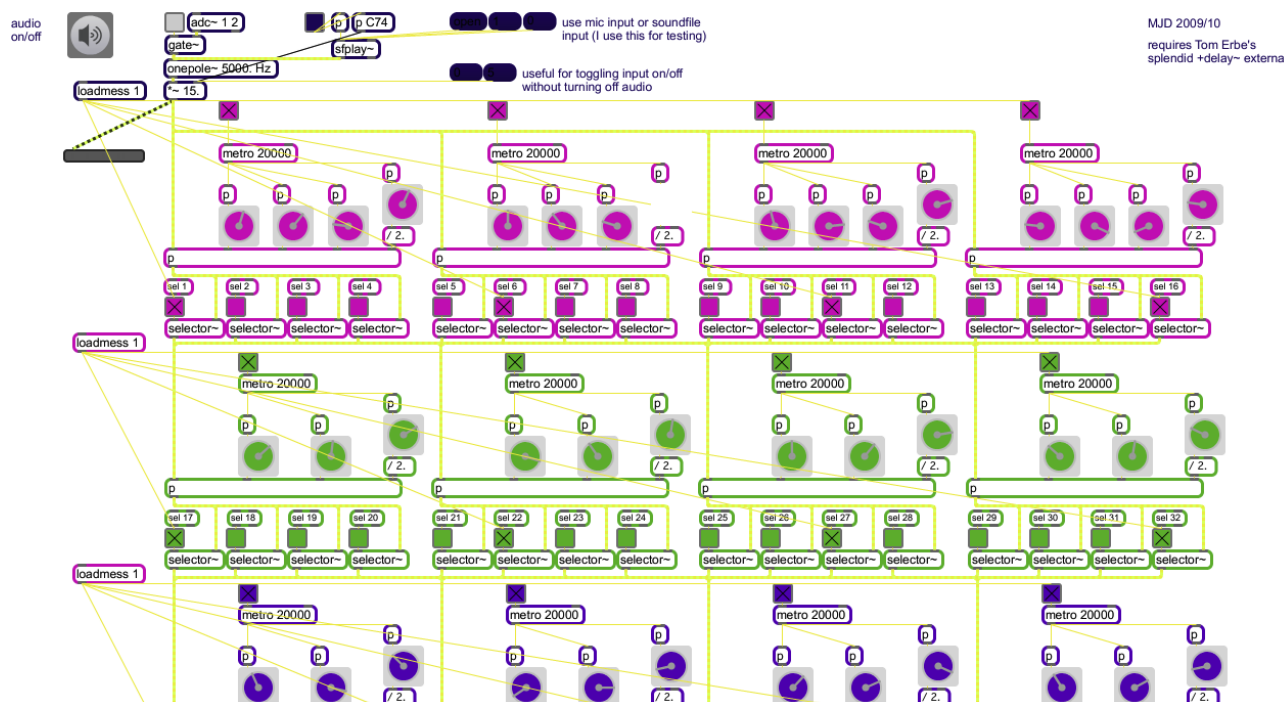


Fig. 49. The DelayNet Max patch. The connections between the four layers of delay lines can clearly be seen.

## User Study

As with the mTable, iPad Topographies, and Vanishing Point instruments, a small-scale user study was carried out. So that data could be compared, the study design and conditions were as similar as possible to the previous studies. Eleven people took part; nine male and two female, aged 18 to 55 years (average 28 years). Two participants were very experienced musicians (ten or more years of experience), three

were moderately experienced (three to ten years of experience), another three had between six months and three years of musical experience, and one had less than six months of prior musical experience.

While participants generally rated the instrument favourably, they also considered it to be the least familiar of all the instruments tested, and one of the most difficult to learn. To these ends, participants variously commented that:

I had never done anything like this before: I would like to watch someone else play it first.

Playing the instrument was really hard but still quite fun.

Maybe [there could be] a manual.

It also seems that most participants intuitively understood that the DelayNet instrument does not try to imitate the close musical control of the traditional (acoustic) instrument paradigm, but instead offers more loosely bounded and indirect influence. Considering what the implications of this looser performer-instrument relationship may be, one participant hints that the reduced (physical) demands may offer increased potential for close listening and moment-to-moment reflection. He commented that:

It's cool to listen to your own sounds so you can improvise over the top [sic].

This directly recalls the comment of Cook (2001; 2009), that some (but not all) performers may have "bandwidth" to spare.

Perhaps more than any of the other instruments, the sounds produced by the DelayNet are not conventionally musical; indeed, the instrument stubbornly resists typical musical features such as melodies, chords, and rhythms. While this

expectational shift posed difficulties for some participants, others commented that:

I would definitely use the sounds in my productions.

[the instrument] would go well with films.

The latter comment is particularly interesting, for it perhaps implies that this participant sees the instrument in terms of texture or atmosphere, rather than conventional music *per se*. Nevertheless, it is quite in keeping with the definition of music as organised sound adopted earlier in this thesis.

## **Reflection and Discussion**

One of the more distinctive features of the DelayNet instrument is its latency between gestural input and sonic outcome (see DVD example: DelayNet: Demonstration). For the unacclimatised, this slow response can be quite disconcerting, for traditional musical instruments tend to react instantly to the application of performance gesture. What is more, the DelayNet not only differs from traditional instruments in terms of its slowness, but also in its extreme lack of stability. Nevertheless, these instabilities and variations conceal an underlying structure and macro-scale tendencies that become intelligible and learnable over time. For example, a combination of ambient (i.e. environmental) sound input and gentle movements of the controller tends to elicit a soft chorus of insect-like chattering from the instrument, while more energetic motions and louder, more directed sound input tend to create more substantial masses of sound. If the sound input is strongly pitched, a range of glissandi-like effects can be quite reliably produced. By adopting a gate metaphor for the performer-instrument interaction, it is possible for the performer to capture and trap sounds in a loop, and then overdub them in real-time. Nevertheless, these loops are rarely smooth or seamless, for their fabric (in terms of both tone and pulse) is constantly re-shaped by

the acoustic properties of the performance space.

After spending around two hundred hours with the DelayNet over a period of several months, the looseness of its performer-instrument interaction started to grow a little tiresome, but the range of sounds produced (especially from such economical means) continued to delight. Thus, the DelayNet found new lease of life as a sound processing/modification system. Whether parasitically inserted into a conventional guitar-based band context (essentially operating as an effects unit), or augmenting background ambience (i.e. a reactive soundtrack to everyday activities), a surprisingly varied stream of sonic textures continued to emerge.

## **Summary**

The DelayNet is a shifting, dematerialised instrument built from a network of 16 variable delay lines that approximate the Karplus-Strong string algorithm. The result is a highly unconventional musical system characterised by instability and a very loose sense of control. The latter characteristic in particular poses serious challenges for those versed in the near-instantaneous responses and precision of traditional musical instruments (Tanaka, 2000), and thus study participants considered the instrument to be relatively difficult to use and learn. However, over time the author also tired of the looseness of the interaction, and the DelayNet slowly evolved into a "hands off" sound modification system rather than an instrument that is played by a performer. This can be considered yet another example of how musical instruments can evolve unexpectedly over time.

## Eden3

Artists and musicians work with philosophers, technologists and scientists to monitor respiration and photosynthesis in trees. The work results in a multi-media experience that links imagination and perception in pursuit of specific experience of another living thing as it reacts and adjusts to the quantity and impact of CO<sub>2</sub> in cities. (Collins and Goto, 2010)

Unlike the other instruments in the portfolio, the Eden3 project represents a concerted interdisciplinary collaboration. However, this thesis will concentrate on my personal contribution, the design of a system for the real-time transformation of plant physiology data into musical output in the sense of organised sound (see DVD example: Eden 3: Eden3 Overview). The concept of this system is illustrated below (see Fig. 50). Thus, for discussion of the environmental and educational concerns of the project the interested reader is referred to Goto (2010), Goto and Collins (2010a; 2010b).

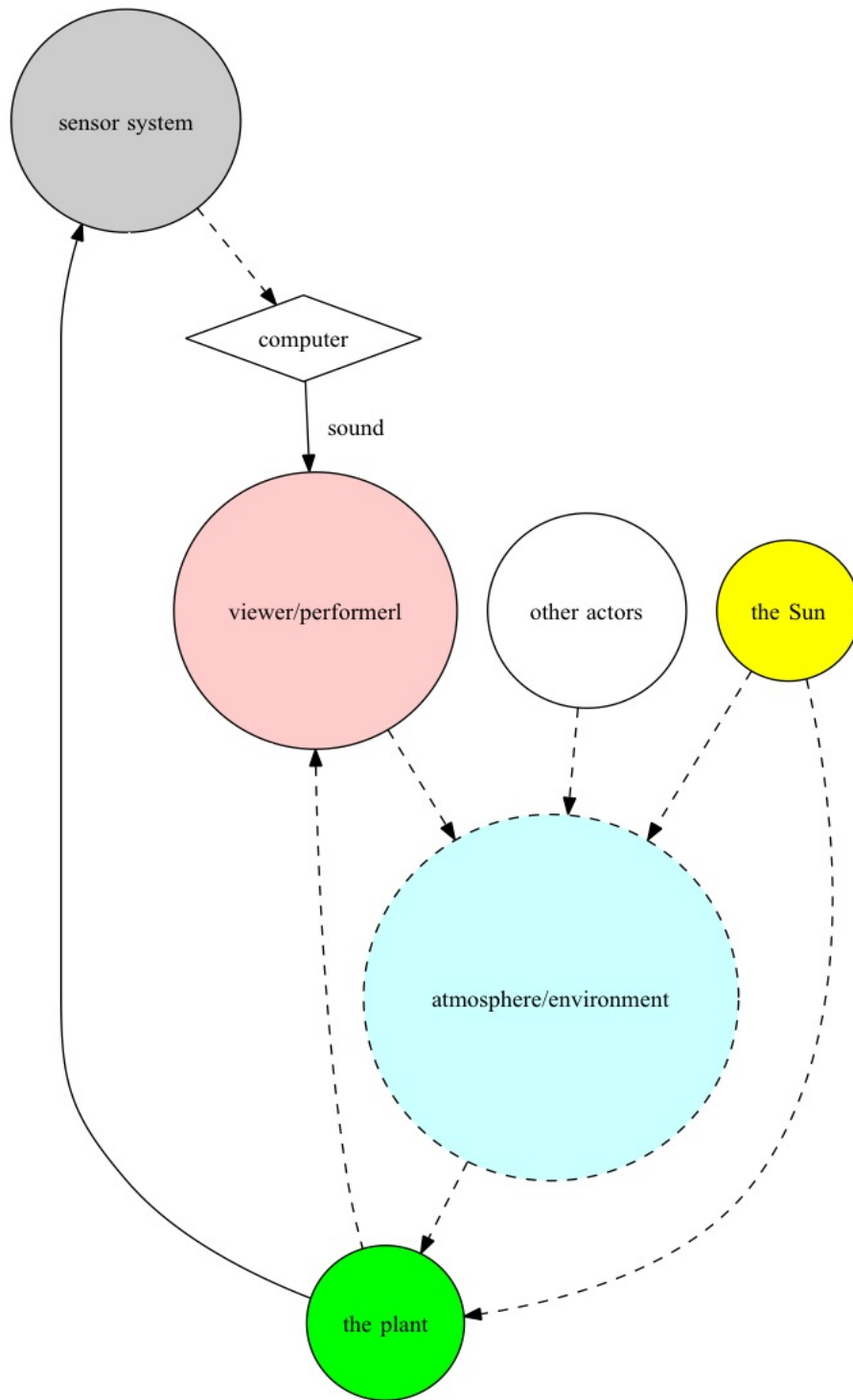


Fig. 50. The interdependencies of the Eden 3 system.

While it is difficult to consider the Eden 3 system a true musical instrument (except under the most relaxed of definitions), it is treated here as a meta-instrument that can add to a further understanding of digital musical instruments and their nature.



## System Design

At the heart of Eden 3 is the plant physiology system. This consists of two parallel and concurrent sensor sub-systems that were developed at the University of Wolverhampton AgLab at Compton (see DVD example: Eden3: Lab Testing). The first sub-system measures carbon dioxide (CO<sub>2</sub>), temperature, and humidity within a sealed leaf chamber (i.e. a controlled atmosphere that is directly acted on by the plant), while the second sub-system measures the same parameters in the external atmosphere, plus ambient light level. The two sets of measurements are then compared. By looking for differences between the leaf chamber and outside atmosphere as the plant consumes CO<sub>2</sub> and releases moisture, the rate of photosynthesis and transpiration can be calculated. The following equations are used:

Photosynthetic rate:

$$\frac{("S151\ CO_2\ (REF)" - "S151\ CO_2\ (SAMP)") * "G265\ Flow"}{(4.431301 * (273.15 + "Air\ Temp"))}$$

Transpiration rate:

$$\frac{(Esamp - Eref)}{(1013.25 - Esamp)} * \left[ \frac{(G265\ FLOW)}{(4.4313 * (273.15 + (AIR\ TEMP)))} \right] * 1000000$$

Where:

Esamp = Sample Humidity

Eref = Reference Humidity

1013.25 = Atmospheric Pressure in mbar (may change daily)

To enable the sensor data to be polled in real-time, the original commercial, closed-source sensor interface hardware was modified to incorporate two Arduino microcontrollers. This enabled the sample rate to be increased from 1Hz to 100Hz. However, the Eden3 system is limited not only by technology, but also the physiological response time of the plant (a few seconds). Thus, while Cook (2001) suggests that faster sample rates are usually necessary for musical applications, 100Hz is considered an adequate temporal resolution for this project.

The raw sensor data is then parsed by a Max patch, with the cooked data then used to calculate transpiration and photosynthetic rates. Transpiration rate is mapped to the pitch and photosynthetic rate to the timbre and amplitude of a collection of virtual strings (again based on the Karplus-Strong algorithm).

...where highest woods impenetrable to star or sunlight, spread their  
umbrage broad. (Milton, in Todd, 1809, p. 103)

The actual pitches played are selected by a sub-patch that, based on Acuma (2011), implements the Self-Similar Melodies of Tom Johnson. The effect is of a stream of notes that climbs over and around simple melodies (see DVD example: Eden3: Headlands Installation).

## **Reflection and Discussion**

While the other instruments in the portfolio are concerned with relationships between humans (performers) and technologies, the Eden 3 project revolves around the relationship between humans and plants, enabled and mediated by technology (see Fig. 51). Therein lies its capacity to surprise and confound expectation. If it were a more conventional musical instrument, Eden 3 may reasonably be expected to

respond instantly to the input of the performer. A delay of a few seconds or more between input and output would likely be considered unacceptable. By contrast, the (incorrectly) presumed time scales of plants range from hours to entire seasons. It is easy to think that, moment-to-moment, they are essentially inert or stable. In other words (to state the obvious), while both respond to human presence and action, expectations of musical instrument behaviours are fundamentally different to those of plants. Thus there is a delight in the unexpected, namely the discovery that this (augmented) plant not only responds quickly to human presence, but that its response can be learned and influenced, if not precisely controlled. Thus, if it may be too much of a stretch to position the Eden 3 system as a musical instrument, it can certainly be seen to possess some instrument-like qualities.



Fig. 51. Tim Collins with the Eden3 plant physiology system.

However, as the performer learns the responses of the system, their relationship with the plant is inescapably altered, and the performer may begin to recognise or share in

the experiences of the plant as a physiological, semi-sentient entity. While this potential for relations between species has antecedents in earlier work by David Last (2008), it is distinct from the manner in which traditional instruments (as inanimate objects) are sometimes anthropomorphised and handed invented personas. It is also quite antithetical to the perceived cold and clerical nature of some computer music paradigms (Monroe, 2003; Stuart, 2003; Rebelo, 2006).

However, the relationship between human and augmented plant is not a simple dialogue but an ecology of influence and interdependence: a host of additional and often transient factors also influence plant physiology and the response of the system. In addition to the type of plant used, these include location, time of day, localised climate, number of passers-by, and the amount of air pollution. In other words, the performer and plant are only part of a more complex, multimodal, and loosely bounded ecosystem. This can be seen as an eloquent metaphor for the DelayNet and Vanishing Point instruments in particular.

The young have also become accustomed to perceptive multi-tasking, to spreading their attention over several layers of experience at the same time. In art, it corresponds to the alliance of several media in order to create either a mutually supporting relationship or an immersive environment. The music provides only one layer of the experience; loosely related visuals, talking and ingesting various stimulants provide the other layers. (Gehlhaar, 2002, p. 5)

Like the iPad used in the iPad Topographies, the Eden 3 system is not a dedicated musical platform: it has additional scientific and educational functions. These include to log sensor data, and to educate the public as to how plants function and are affected by human presence. With compromise perhaps inevitable in a project of such diverse concerns, it is interesting to consider whether there continues to be a place for dedicated musical devices. Alternatively, in the present era of interdisciplinarity and

shared attention, must musical instruments also be able to contribute to areas outside of music, and therefore contribute a kind of added value. Before the latter is accepted, the cost of this diffused focus must be carefully contemplated. If, at its most successful, interdisciplinary working can be mutually supportive of the individual interests and concerns accommodated within, new issues are raised. For example, the aims of and language used by artists, musicians, and scientists can differ considerably. This can hinder the agility and direction of the development process. Moreover, after Jon Bird and Paul Marshall (2009), it is easy for the carefully constructed interdisciplinary working of the Eden 3 project to feel artificial and contrived. As the authors highlight, with reference to the influence of the VNS and hipDisk on ubiquitous computing, influence on other domains may be unplanned and unexpected, creeping up slowly over decades.

## **Summary**

Through the real-time translation of plant physiology processes into musical output, Eden 3 enables new insights into the relationships humans have with plants. At its core is a multi-sensor, computer-based system created from modified commercial hardware. Although by musical standards the response of the system is slow and imprecise, the relationship between human (performer) and augmented plant is unusually empathetic. The closeness of this relationship is far removed from and perhaps even antithetical to the perceived coldness of some computer music paradigms. Nevertheless, it is not a simple monologue, but a significantly more complex and loosely bounded ecosystem of co-influences and interdependencies.

## General Discussion

While the performer-instrument relationship has been discussed in some detail (see Chapter 3), it is only now that this thesis can start to suggest how Tudorian digital musical instruments can be played and what the most productive approaches may be, for these aspects can only be explored once the instruments have been designed and built. While these initial findings will continue to mature and evolve over time, the hope is that they will provide a useful foundation for future performers and researchers.

I found it surprising that while the instruments in the portfolio often represent substantial departures from the familiar in terms of their appearance and sound, many participants (regardless of the new instrument they played) attempted to impose old (i.e. traditional) performance strategies. These included playing major, minor, and chromatic scales, and well-known musical phrases (see DVD example: iPad Topographies: User Study: chapter 1). The reasons for this are uncertain, but faced with an unfamiliar instrument it is plausibly a means of orientation; what Leigh Landy (1994) calls a "something to hold onto factor" (SHF), or the result of engrained, culturally constructed expectations as to how instruments should be played and the sounds they should produce.<sup>68</sup> With the instruments quite obviously (and unanimously) unsuited to these techniques, some participants continued to persevere, while others began to explore more innovative approaches. The latter would appear necessary in order to make the most of the new instruments. One approach found<sup>69</sup> to be particularly resonant was the exploration of perceptual boundary (i.e. between) conditions. This includes, for example, the thresholds between silence and sound, pitch and rhythm,<sup>70</sup> and stasis and motion. It is important to note that the fine-toothed control needed would not be possible if MIDI (with its 128 discrete steps) was used

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<sup>68</sup> It is prescient to consider the comments made by Cage regarding the theremin, some eight decades earlier (see Chapter 2).

<sup>69</sup> From the perspective of designer-performer.

<sup>70</sup> The pitch-to-rhythm glissando in Karlheinz Stockhausen's *Kontakte* is a good example of this.

instead of OSC. The instruments can therefore be considered in terms of the exploitation of technology-specific affordances.

Another pertinent strategy has been the exploration of the extremes of perception. For example, I would first isolate a sequence of sounds, then try to repeat it as quickly or slowly as possible. Subject to human inaccuracy and fallibility, this would often be warped and distorted, sometimes beyond the point of legibility.

Interestingly, there is evidence that, without additional signposting, participants were exploring similar strategies (see DVD example: iPad Topographies: User Study: chapters 4 and 5). Thus, to some extent, it appears that these techniques may be suggested by the contours (or perceived affordances) of the instrument designs. In other words that the instrument designs (albeit some more successfully than others) communicate to the user at least some of the intentions of the designer.

These performance strategies can be related to the text-based event scores of 1960s Fluxus, whereby textual instructions are given for performative events (Potter, 2000, p, 34). They can also be more generally related to the trope towards more open and experimental models of music in the second half of the 20th century, defined by Cage as:

an experimental action is one the outcome of which is not foreseen. (Cage, in Cox and Warner, 2002 p. 207)

By re-contextualising the instruments in the portfolio in this way, they are effectively detached from the expectations built up over decades or centuries around more traditional musical instruments. However, this raises questions as to what mastery and virtuosity might mean in this new context. For example, how can a performer hope to master an instrument whose response cannot be anticipated? As yet, it is difficult to answer such questions with any degree of certainty. For example, there is no immediate correlation between the previous musical experience of participants, their (self-rated) progress in learning to play the new instrument, and how likely they

considered themselves to play the instrument again in future (see Appendix C). This could indicate that the new instruments are so disruptive<sup>71</sup> that traditional instrumental skills are negated. However, more longitudinal research is needed to help develop more reliable understanding of this area.

If it is obvious that the instruments in the portfolio were not equally successful, it is also apparent that within the same instrument some topographies were better received than others.<sup>72</sup> Nevertheless, each instrument and topography illuminates one or more aspects of Tudorian digital musical instruments, thereby offering a kind of meta-value. Also, despite their sometimes substantial differences, there is often considerable overlap. This overlap has helped to piece together a more rounded understanding of the subject.

As part of the continuous process of self-reflection, the influence of the earlier findings is already found in the more recent work in the portfolio. The iPad Topographies for example are a direct response to the outcomes of the mTable work. However, even the relatively minor refinements to the design of the later topographies appear to have made a significant difference to the user experience, for participants rated the iPad Topographies more favourably than its predecessor in most of the areas surveyed. Other lines of influence may be less direct but are nevertheless important, and, beneath the organisational idea of scale developed at the start of this chapter, the portfolio instruments may also be thought of in terms of a more rhizomatic labyrinth of ebbs and flows. For example, the restrictions imposed by the fixed 2-D plane of interaction in the Vanishing Point instrument initially inspired the more freeform interaction offered by the DelayNet instrument. Then, after several months spent learning to play the DelayNet, a sense of wanting something different to its indirectness<sup>73</sup> and sluggishness directed the development of the Drone topography for the iPad towards directness and intimacy. Other relationships between the instruments are more incidental. For example, the Scanners and Eden 3 projects took

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71 i.e. radically different to their predecessors.

72 Although it is too early to entirely rule out the less successful topographies, this offers a useful initial indication of playability, musicality, and potential longevity etc.

73 There is little sense of causality and so the performer can become lost.



place approximately contemporaneously. As apparent extremes of digital musical instruments their juxtaposition provided a number of interesting contrasts, particularly in terms of performer-instrument intimacy.

The Drone topography was the last of the instruments in the portfolio to be completed and in many ways represents a culmination of the practice and its associated theories.<sup>74</sup> Its sense of intimacy stems primarily from the direct manner in which the performer appears to act on the means of sound generation. While this is inherently an illusion, for digital bits are obviously intangible and can only be manipulated indirectly, it is a convincing one. To my mind at least, the performer-instrument interaction recalls the sensation of playing electronic circuits such as the STEIM (2004) crackle box, for while there is a close connection between action (input) and sound (output) the relationship can be highly disproportionate: minute gestures can produce vastly expansive sounds. Related to this, the Drone topography notably avoids the temptation to over design. In other words, it does not try to incorporate too many features or layers of interface complexity, but to allow the innate character (or grain) and subtleties of the instrument to come through.

Perhaps most importantly, the Drone topography was not only positively received by participants in the user study, but also has become my own preferred choice of instrument. Thus, while a fortuitous meshing of components and expectations cannot yet be ruled out, there would seem to be a link between qualities such as directness, responsiveness, and intimacy of interaction and the potential for sustained (i.e. longer-term) performer-instrument engagement.

## Summary

Informed by the framework introduced at the outset of this thesis and further developed in Chapter 2, a series of seven new digital musical instruments have been

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<sup>74</sup> i.e. of all the instruments it most succinctly encapsulates the Tudorian qualities proposed in Chapter 3.

presented, critically evaluated, and discussed in turn. After an initial focus on instrument-specific observations, the chapter then turned to consider the instruments more generally and collectively. Thus, the scene is set for the fifth and final chapter which draws the findings of this research together and offers a series of conclusions.

# Chapter 5

## Conclusions and Future Work

### Overview

The focus of this PBR has been the development of a framework for digital musical instruments, the role of which is two-fold. First, it has helped to understand and critically assess developments past and present. These range from early electronic instruments and the live electronics of Tudor, to modular (analogue) synthesisers and the impact of MIDI, and the NIME community of the last decade. Second, the framework has informed the design of seven new instruments, and provided a basis for their testing and evaluation. As an integral part of these processes, this work has reviewed and built on previous research. Now, in this final chapter, it is time to pull the different facets of the research together, for it to be situated in and contribute to wider thought and practice.

After a summary of the thesis so far, the hypothesis proposed at outset is reconsidered in light of the work undertaken. In particular, the results of the previous chapter will be used as means by which the Tudorian framework can itself be re-evaluated. Where limitations or deficiencies are identified, these are made clear to the reader and the original claims revised or depreciated as appropriate. The conclusions are followed by a summary of the contributions made by the research to digital musical instrument practice and knowledge. The thesis then closes with more speculative discussion of possibilities for future work.

## Research Summary

This research has developed a train of thought from hypothesis through to conclusion. To this end, seven digital musical instruments have been designed, implemented, and evaluated in order to test the following hypothesis:

[that] The live electronics of David Tudor may offer a more appropriate and productive foundation upon which to base our understanding of digital musical instruments. In other words that the Tudor electronics may help to critically consider and discuss digital instruments, and aid in their design.

This in turn informed the following research questions:

- How is prior and current art in the field deficient, and how does it fail to meet the demands of performers and performance?
- Which qualities and characteristics are desirable in digital musical instruments, and which aspects of previous (acoustic/electric/electronic) instruments should be maintained and discarded?

In particular:

- Can a Tudorian framework help to understand digital musical instruments, and aid in their design?
- What can be discovered about the digital musical instruments created by playing them, and how might these findings be more widely applicable?

In answering these questions, this research has primarily focussed on the field of digital musical instruments. Nevertheless, care has been taken also to consider the main historical precursors and relevant work in related domains. Chapter 2 for

example explored the evolution of musical instruments from the introduction of electricity in the late 19th century to the present day. Having navigated its way through the histories of electro-mechanical, analogue electronic, and computer-based instruments, the chapter culminated in an anatomical survey of the digital musical instruments presented at the NIME conferences from its foundation in 2001 until the present. Building on earlier work by Marshall (2009), it found there to be both diverse use of the same few technologies<sup>75</sup> and a tendency to imitate the acoustic paradigm. It suggested that these have contributed to a lack of a distinct identity for digital musical instruments.

Informed by the qualities identified as desirable, the second part of the chapter then presented a novel framework as an aid to understanding and designing digital musical instruments. This included the following aspects:

- Emergence
- Nuance
- Skill and skilling
- Plasticity and meta-plasticity
- Expression, expressiveness, and spectacle
- The human turn
- (The nature of) experience
- Long-term engagement, learning, and mastery

In order to test the framework, a continuum of seven new instruments were conceived, designed, and implemented. These were presented and discussed in Chapter 4. In order to evaluate the new instruments, the personal experiences of the author (as designer-performer) were supplemented with informal, small-scale design studies in order to provide more rounded, multi-faceted insight. The chapter

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<sup>75</sup> i.e. the technological basis underpinning the instruments is extremely flexible, and allows for endless possible variations.

culminated with the suggestion that, of all the instruments, the qualities considered aspirational are most eloquently encapsulated by the Drone topography from the iPad Topographies.

## **Conclusions: Assessing the Tudorian Framework**

Underpinning this thesis is the idea that the instruments in the portfolio (Chapter 4) are intrinsically imbued with the framework (developed in Chapter 2) from which they are derived. Thus, after evaluating these instruments in the previous chapter, an initial assessment can now be made of the framework itself. The thesis opened with the proposition that digital musical instruments could benefit from more characterful and cohesive design, influenced by the practice and thought of Tudor. However, over the course of this research it has become apparent that some aspects of the framework are more successful, durable, and appropriate for the digital musical instrument context than others. Thus, to enable finer consideration, the framework will now be further dissected. The main points of the conclusion relate to:

- diversity;
- consistency;
- unpredictability and active listening;
- the designer-performer (and the relationship between performer and instrument);
- a digital musical instrument ecology.

One of the defining characteristics of digital musical instruments is the diverse range of skills demanded of those who design, make, and play them. It is therefore perhaps quite unexpected and surprising that, over the last five years, my time and attention

have not felt diluted or thinly spread. Rather, the apparently varied activities of design, composition, and performance, have become fused in a singular and cohesive digital musical instrument practice.

Another defining characteristic of digital musical instruments is the extraordinary diversity of the instruments themselves. Yet if this diversity sets digital musical instruments apart from the homogeneity of more mainstream electronic instruments (after the widespread adoption of MIDI), it also means that any framework imposed, however flexible, is likely to exclude some instruments (i.e. one size does not fit all). There is thus an acceptance that (outside of this research) some digital musical instruments may be better served by alternative propositions, and that the framework proposed here is only one of multiple possibilities. Indeed, the last few years have seen digital musical instrument paradigms proposed by Armstrong (2006), Marshall (2009), and Bennett (2010), all of which essentially maintain traditional (i.e. acoustic) instrumental paradigms. Thus, if this research was initially conceived as essentially a reaction to and rejection of laptop music performance practices, over time it has evolved into a more nuanced extension to the burgeoning digital musical instruments field.

At a component level however, the sheer number of arbitrary combinations (i.e. micro-scale diversity) makes it difficult to develop a sense of consistent instrument character, for the experiential properties of one component can easily override those of any other. Moreover, the intention of the designer and the experience of the performer can diverge considerably. Thus it is possible for the experience of an instrument to be jarringly disjointed, even if it is conceptually coherent and clearly defined. The problem is therefore one of articulation/interpretation, and is perhaps comparable to the distinction between real and perceived affordances proposed by Norman (1999; 2011).

These discrepancies are often discovered at the testing stage (hence the importance of testing), and indeed there is some evidence of this from the user studies. For example, while the DelayNet responds to the input of the performer very

slowly (it could take up to 20 seconds to respond) and is therefore quite unlike a traditional musical instrument, two participants praised its quick and nimble response. While these differences could simply be attributed to poor design or personal taste, they may also imply that the language and terminology needed to think about and discuss digital musical instruments has not been widely disseminated. There are already precedents for this in related fields. Caleb Stuart (2011, p. 13) for example notes that art critics (trained in painting, sculpture, photography and film) have struggled to accommodate the recent sonic turn in the visual arts, while in relation to laptop music performance Cascone (2002) laments that the audiences lack the vocabulary to appreciate its performer-instrument interaction. These issues must be addressed if digital musical instruments are to become more widely accepted and adopted. Indeed over the longer-term, they may be as important as how the instruments are designed and played.

One possible solution is the notion of SHFs developed in the context of electroacoustic music by Landy (1994) and Rob Weale (2006), and mentioned in the previous chapter. SHFs aim to increase the accessibility of electroacoustic music by consistently incorporating familiar and well understood musical features into what is for many people a disconcertingly alien performance paradigm. These act as reference points, providing a route into the work for the uninitiated. SHFs may be especially useful for digital musical instruments that incorporate generative systems. Although by nature, some aspects of such systems are fluidly unpredictable, it appears helpful for other aspects to remain fixed or stable if the instrument is to be comprehensible. In other words, the unpredictable needs to be balanced with the predictable. The DelayNet instrument and Android topography for the iPad, for example, appear to have leant too far towards unpredictability. This ultimately comes at the expense of consistent instrumental character and intimate qualities such as directness, responsiveness, and immediacy, for as output possibilities increase, the designer must take a broader, macro scale approach: it quickly becomes unfeasible to focus on microscopic subtleties and details.



What is more, if generative systems are in some senses uniquely problematic, it may be that their importance was also initially overstated. For instance, the study participants were apparently entirely indifferent to generative systems.<sup>76</sup> Moreover, it may be that the heightened opportunities for active listening afforded by digital musical instruments are similarly able to produce music that is ever-changing and different every time it is heard. As Roden describes, this alone allows for considerable diversity of experience:

Marcel Duchamp spoke of the viewer completing a work of art and that a work of art has no meaning without a viewer to bring meaning to it. And so I think, as active listeners, we can become 'composer listeners', as we decide what sounds in the world we are going to ignore and what we will choose to listen to as music. Anyone who has stood at the side of a small stream, lost in the sounds of water flowing over the stones, has already done this. (Roden, in Stuart 2011, p. 216)

In the context of digital musical instrument performance, the listener may opt to vary their attention between:

- the overall field of sound;
- a single line or stream of sound events;
- microsound and other sonic minutiae.

This auditory emphasis represents a reversal of the visual bias of western culture proposed by Marshall McLuhan:

Western man thinks with only one part of his brain and starves the rest of it.  
By neglecting ear culture, which is too diffuse for the categorised

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<sup>76</sup> They were not mentioned by a single participant.

hierarchies of the left side of the brain, he has locked himself into a position where only linear conceptualization is acceptable. (McLuhan, in Cox and Warner, 2002, pp. 67–72)

The suggestion is not that the visual modality is redundant, but rather that use of non-traditional mappings renders it fallible and therefore secondary to the auditory. Moreover, visual spectacle is still able to contribute what Chion (1994, p. 9) calls added value, particularly if it occurs as a result of necessary gesture (i.e. an additional layer of interest may be created without any additional expenditure beyond that needed to play the instrument).

The increased importance placed on listening (particularly in a field so heavily invested in technology) also serves as a useful reminder of both the capabilities of the human auditory system and the prescience of avoiding unnecessary complexity. This is closely related to the notion of simplicity, considered here as the inverse of complexity. Simplicity has been the subject of recent work elsewhere. However, while it is praised by John Maeda (2006), Norman (2010, p. 63-89) warns that any notion of simplicity is complicated by circumstance and context. Indeed, there are a number of reasons why absolute or outright simplicity may not be desirable in a digital musical instrument context. Firstly, simplicity implies that an instrument may be too easily mastered and therefore quickly become prosaic and dull. As noted by Jordà (2005), depth and the potential for sustained engagement are closely tied to the presence of complexity. Simplicity may also suggest a limiting of expressive possibilities. For instance, the interface of the iPod (classic) offers a lot of functionality from a single click wheel and small visual display, but can essentially be used in only one way, and thus there is little opportunity for expressive nuance or subtlety. Finally, simplicity may suggest that much of the sophistication of an instrument is hidden and inaccessible. This has implications for the spectacle and reception of performance, as (like the laptop music performance case discussed earlier in Chapter 2) the performer-instrument message may be concealed from or

incomprehensible to the audience. All the same, if outright simplicity cannot be considered desirable in this context (i.e. digital musical instruments should not be *simplistic*), it is perhaps that digital musical instruments must be simple enough, for too much complexity (particularly during initial engagement) can be irksome and similarly discourage sustained participation.

In the monological models sometimes assumed to be present in digital musical instruments, the flow of information is unidirectional, and there is a linear sequence of cause and effect from performer to instrument (Brennan, 2012). That is, the input of the performer stimulates the interface of instrument. This acts on the means of sound generation (the relationship is artificially constructed), producing sound output. However, monological models do not account for the contribution of the instrument. For instance, the Vanishing Point instrument does not simply respond to the performer, but actively resists and continuously challenges them (i.e. it does not passively submit to the performer). Thus, the performer-instrument relationship may be more productively described in terms of a dialogue, whereby the performer not only acts upon, but also actively listens and responds to the unpredictable output of the digital musical instrument. The interactions between the two can be complex and to some extent unforeseeable, but their nature is perhaps similar to the relationship between performer and (experimental) acoustic instrument described by Stapleton (2006):

the unpredictable nature of the instruments is not always a surprise which demands one's conscious attention, but rather that the instruments afford a broad (but learnable) range of inconsistent variations. Further, most improvisers will acknowledge that they can learn to spontaneously make creative use of the moments when they are surprised by unforeseen sonic occurrences. Therefore, the experienced performer learns to move with, and respond to, an unfolding musical dialogue in a predominately non-reflective manner.

The duet between myself (with the Vanishing Point instrument) and an improvising guitarist suggests that this dialogical model may also be extended to relationships between performers, with listening acting as a bridge or common ground between the digital and acoustic domains. With multiple performers the dialogues are potentially richer and more numerous, for sounds may be created and responded to from as many different perspectives as there are contributors.

However, to enter further into an auditory field poses some unique challenges, for it is at once deep, unbounded, and promiscuous. A useful analogy is provided by the post-phenomenologist Don Ihde:

Ordinarily I am concerned with - focus my attention on - things or "objects", the words on a page. But now I note that these are always situated within what begins to appear to me as a widening field which ordinarily is a background from which the "object" or thing stands out. I now find a purposeful act of attention that I may turn to the field as field, and in the case of vision I soon also discern that the field has a kind of boundary or limit, a horizon. The horizon always tends to "escape" me when I try to get at it; it "withdraws" always on the extreme fringe of the visual field. It retains a certain essentially enigmatic character. (Ihde, 1977, p. 38)

Indeed, the DelayNet, Eden3, and Drift topography for the mTable are so unbounded and openly permeable as to be leaky: the performer becomes acutely aware of the bi-directional flows between performer, instrument, and environment.

In addition to these adjustments to the performer-instrument model, a number of more concrete possibilities exist for improvements to the quality of interaction and the user experience. These relate to:

- the slowness of microcontrollers;

- discrepancies across different implementations of the OSC protocol;
- a lack of haptic sensation in multi-touch technologies.

Micro-controllers are found in and of central importance to many musical interfaces (including the ServoString and Eden3 instruments). Since its development in 2006/7, the Arduino platform has become by far the most popular choice among the DIY community (Torrone, 2011). However, if the Arduino is in some respects ideal – it is extensively documented, available under an Open Source license, and benefits from an active community of users and developers – it is hindered by the relative slowness of its serial connection (Measuring Stuff, 2010). While this may not be an issue in all applications, it is problematic in a digital musical instrument context for it restricts how quickly sensors can be read and actuators manipulated. As Marshall (2009) states, this has a fundamental effect on the quality of the performer-instrument interaction and the experience of the performer. Indeed, it is for this reason that the Arduino is not used more extensively in the portfolio instruments.

One alternative to the Arduino is the Teabox system by Electrotap (2009). This system was developed specifically for musical applications, and is capable of audio rate operation and communication. However, it is more expensive than the basic Arduino by a factor of ten, its hardware and software are closed rather than open source, and it has a far smaller community of users. It also has fewer channels of input/output (IO), and lacks the extensibility of the Arduino shield paradigm. Meanwhile, more established alternatives to the Arduino such as the PIC and Basic Stamp also rely on a serial interface, and therefore suffer from similar issues of slowness, as well as potentially more difficult to program. Thus, a hybrid of the Arduino and Teabox is desirable; in other words, a sensor interface that is both open source (in hardware and software) and able to operate at or near audio rates ( $\geq 1000\text{Hz}$ ). To ensure maximum flexibility, the option to choose between both wired (e.g. USB) and wireless (e.g. WiFi) methods of communication is vital, while an Arduino-like shield system could be used to expand sensor/actuator IO where

required. Finally, for many musical applications concurrency would also be useful (see Jadud, Jacobsen and Sampson, 2011). For instance, it would enable sensors to be read in parallel to sound generation.

Although essentially intangible and perhaps under-appreciated as a result, the choice of communication protocol is similarly important in determining the quality of the performer-instrument interaction and the possibilities of an instrument.

Throughout this research OSC has shown itself to be a better choice than MIDI in almost all circumstances. For example, it offers a much more flexible message scheme that does not impose any particular scale or degree of precision, is capable of greatly increased data transmission rates, and enables multiple messages to be sent and parsed simultaneously (Phillips, 2008). However, inconsistencies between different implementations of OSC continue to pose problems. For example, the popular ReacTIVision and CCV multi-touch clients are incompatible because the output of the latter contains additional parameters that the former is unable to parse (Coenen, 2009). While this is just one localised example, it betrays a wider pattern of minor incompatibilities. At present notably few OSC-enabled devices and applications work together in a plug-and-play manner. However, if OSC is to succeed MIDI as the primary glue for both digital musical instruments and music technology more generally, its everyday use must be as convenient as possible; not only for designers, builders, and tinkerers,<sup>77</sup> but also performers and other end users who may not wish to concern themselves with such overtly technical aspects.

The notion of a disconnect between intended and perceived messages has been discussed earlier in this chapter. Another example of this is the pristinely smooth surfaces found in most multi-touch technologies. While based around touch input they in fact offer little haptic sensation and the performer must instead rely on the eye as the primary means of navigation. This is potentially problematic, for as Bret Victor (2011) notes, to let the eye dominate is to miss out on much of what the hands have to offer:

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<sup>77</sup> For the reasons set out by Michael Norton, Daniel Mochon and Dan Ariely (2011).

Is that so bad, to dump the tactile for the visual? Try this: close your eyes and tie your shoelaces. No problem at all, right? Now, how well do you think you could tie your shoes if your arm was asleep? Or even if your fingers were numb? When working with our hands, touch does the driving, and vision helps out from the back seat. (Victor, 2011)

While there have been efforts to develop more tactile, pressure sensitive multi-touch surfaces across both commercial (Touch User Interface, 2009) and academic (Smith *et al.*, 2007; Freed, 2009; Essl, Rohs and Kratz, 2010; Fyfe *et al.*, 2010) realms, these have typically been limited in terms of their size, or ability to display visual information (this is still useful, even if it is not of primary importance). It is perhaps telling that none of these developments have been widely adopted, and there continues to be much scope for future work in this area.

If these are just some of the steps required to take digital musical instruments forward (there are likely many others), it is necessary to consider that the contribution of any individual, no matter how substantial or significant their impact, is ultimately limited. However, if the designer-performer of the 1960s (i.e. Tudor) primarily connected in person (i.e. face-to-face) or by the postal system, thereby restricting their reach, the designer-performer of the internet era is characterised by an unprecedented connectedness, whereby information, materials, and communities of like-minded others are accessible as never before (largely independent of location and means). While the majority may be inexperienced amateurs, interspersed with experts, they represent a collective of considerable potential and ability. Thus, they are well placed to accomplish the longer-term and larger-scale aims of this research. There would certainly appear to be interest in the designer-performer route, not only from participants in the user studies, but also (more anecdotally) outside of this research project:

There are more than 100,000+ Arduinos on the market, and by my estimates, a lot more when you add in the derivatives (approximately 150K as of 2/2011). Within the next 5 to 10 years, the Arduino will be used in every school to teach electronics and physical computing – that's my prediction. There's no going back. (Torrone, 2011)

With their fusion of previously distinct activities, the contemporary designer-performer can also be situated within the context of a broader trend towards self-sufficiency. Within digital music culture (i.e. beyond digital musical instruments), it can be identified that an increasing number of artists have not only involved themselves in all stages of the musical process but undertaken them themselves, from creative concept and musical production to distribution and promotion. The likes of Cascone, Robert Henke (Monolake), Richard Devine, John Burton (Leafcutter John), and Matthew Davidson (Stretta) all exemplify this kind of self-sufficiency. A typical workflow may be:

- design and implement a digital musical instrument or performance system;
- compose music for or create music on the instrument;
- record, edit, mix, and master the music created;
- distribute the music online;<sup>78</sup>
- perform the music live, in part as a means of promotion for the recording;
- produce associated sound/audiovisual installations;
- undertake pedagogical work (lectures, workshops, etc.), whether formal or informal.

It is clear that if traditional distinctions are maintained, it can be difficult to fully comprehend their contributions. Indeed it may be in this ability to shape the entire musical process and experience for oneself that (at least part of) the expressive power

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<sup>78</sup> For more information on the music industry in the era of Web 2.0, the reader is referred to Gehlhaar (2002), Chris Anderson (2006), and Gerd Leonhard (2008).



of digital musical instruments is found. Thus, expression can be reframed not just in terms of what is done with an instrument, or how it is played, but as a complex synthesis of interconnected activities that occur at different time frames (i.e. both real-time and non-real-time activities).

Thus, digital musical instruments can be situated within an ecology that incorporates contextual, human (conceptual and experiential), technical, instrumental, and musical aspects, plus all of the flows between them. Ecological approaches have been explored in related fields, most notably by Eric Clarke (2006) and Jonathan Bishop (2007). They have also been briefly explored in the context of digital musical instruments by Axel Mulder (2010), but the concern remains that audiences steeped in what Cascone (2002) terms pop spectacle may be ill-prepared for a shift to a multi-faceted, non-panoptical model of artistic expression.

Based on the ecological model of HCI proposed by Bishop (2007),<sup>79</sup> a digital musical instrument ecology can be constructed in terms of the following layers:

- broader influences on designers, performers, and audiences. These range from politics, law and regulation to economics, and socio-cultural factors. There are too many to list exhaustively, but examples include:
  - the effect of patents, copyright law and international trade (i.e. the production and supply of manufactured components) on instrument design and implementation;
  - the effect of licensing laws on music events and venues;
  - media channels that drive mass and niche tastes.
- the ideas, intentions, and other thought processes of the designer-performer;
- the dialogical interactions of the designer-performer and instrument;
- the perceptual environment occupied by the performer/s, instrument/s and audience.
- recordings made of the performance (i.e. performance artefacts), and the channels by which they are shared.

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<sup>79</sup> Itself informed by the earlier proposition by Gibson (1979) that an active observer picks up information directly from the environment and therefore intermediary processes are unnecessary for visual perception (Goldstein 1981).

This digital musical instrument ecology spans multiple scales, from the socio-political to the individual, the instrumental, musical, and technological. Influence between layers is bi-directional (note that the dialogical relationship between performer and instrument discussed earlier in this chapter is incorporated), and often fuzzily defined. Moreover, it must be emphasised that the layers are not equally sized (there are intersections between individuals and multi-national industries), and the channels of communication between them are not necessarily even in their number or bandwidth.

Nevertheless, it must be remembered that digital musical instruments are still in their infancy, and it is likely that even this new model will need to be subsequently revised and refined. This is not a symptom of weakness or sign of inadequacy, but rather evidence that there remains much to be explored and discovered.

## **Summary of Conclusions and Research Contributions**

The framework developed in Chapter 2 has been used as an aid to understanding and designing digital musical instruments. These instruments were then presented and evaluated in Chapter 4. Now, in this final chapter, the following conclusions are drawn:

- digital musical instruments are extremely diverse, and their nature remains unfamiliar. This poses significant difficulties in terms of their consideration and discussion;
- a number of technological issues currently hinder the performer-instrument experience. These include the slowness of the Arduino microcontroller, inconsistencies between different implementations of OSC, and the lack of haptic sensation in current multi-touch technologies. The contemporary

designer-performer is shown to be well placed to drive these and other improvements;

- the importance of generative systems was initially over-stated, for the act of (active) listening alone allows for considerable possibilities of interpretation. This auditory focus opens up the possibility of considering the relationship between performer and instrument in terms of a dialogue. This is seen to be a productive model that may also extend to digital musical instrument performance with more than one performer;
- simplicity may not be desirable on grounds of effort, performance spectacle, and the potential for sustained engagement. Yet, complexity is equally problematic, for it may frustrate and discourage participation. It is therefore perhaps that digital musical instruments should be simple enough (but no simpler).
- digital musical instruments can be situated within a broader ecology of interconnected real-time and non-real-time activities across multiple scales.

The contributions made by this research into theory and practice relate directly to the aims and objectives stated in the introduction to this thesis. They can be summarised as:

- a definition of digital musical instruments, and associated terminology that can aid their consideration and discussion as a singular field of activity;
- the identification of inadequacies in existing instruments, and the subsequent need for approaches to digital musical instruments that are both more cohesive and distinct from traditional instrumental paradigms;
- informed by qualities identified as prescient and desirable in the live electronics of Tudor, the development of a conceptual framework that can perform a dual role. Firstly to help understand and question digital musical instruments, and then to aid and inspire their design;

- an initial assessment of the suitability of the framework in relation to its intended purpose through the comparative evaluation of its practical outcomes. In lieu of a definite or established method for the application of theory to practice, these represent a continuum of new instrument designs;
- the subsequent revision and extension of the framework (particularly in terms of the performer-instrument relationship) in order to incorporate new insight and understanding.

This thesis will now close with an additional contribution of possibilities for future work.

## **Future Work**

While the Tudorian paradigm offered by this research represents a small step forward for the field of digital musical instruments, other paradigms will surely emerge over time. Given the perils of futurology, this thesis will not attempt to predict what these might be. It will instead consider how the findings of this research might be applied to related domains; and real-time visual performance and gesture/motion-controlled video games in particular.

While there are some obvious similarities between (computer-based) visual performance systems (see Momus, 2009) and digital musical instruments, and cross-modal software such as MaxMSP has further blurred distinctions between the two, there remain distinct differences between the two at a perceptual level. For example, the eye operates at much slower rates than the ear (Barry, 2010), but takes in more detailed information with each snapshot. It therefore has a capacity for line and shape that the ear cannot match. Thus it is problematic that visual performance currently borrows the interfaces of DJing and minimal techno so extensively (see Fig. 52), for these favour temporal manipulation above all else (SOLU, 2004). There is typically

little provision for the creation and manipulation of images in real-time, and thus performers are afforded access to only a small subset of possibilities.



Fig. 52. Dj Radar @ Palamartino #2 (von\_boot, 2008).

Image creation remains closely related to drawing and painting; activities in which humankind is immensely experienced.<sup>80</sup> Thus, if more appropriate interfaces are to be developed, it makes sense to leverage these skills. It is possible to imagine the development of domain-specific pen, brush, and tablet-like tools, perhaps combined with current time-based paradigms. These are already established in a musical context (Kang and Chien, 2010) and the recent offerings of the Adobe Photoshop development team for the iPad (Rawson, 2011) show promise to this end.

[W]hen you stop to think about it, Kinect is as amazing as - perhaps even more amazing - than Nintendo's glasses-free 3D gaming. Kinect turns you into a controller. Standing in front of the television you just need to move,

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<sup>80</sup> Like music, visual communication dates back to prehistoric times.

without holding a thing, to play a dance game, play sports, do yoga, exercise, or have an adventure. Kinect transforms those movements very quickly into the motions of your on screen avatar. It's unsettling when you think about it, but it happens so quickly, so effortlessly, that you rarely do think about it. You just play. (Kotaku, in *Changed*, 2010)

Having largely exhausted the push for graphical fidelity, there has been much recent interest in the area of motion-controlled video games, with Nintendo, Microsoft, and Sony all offering broadly comparable systems. The Nintendo Wii and Microsoft Kinect (Trenholm, 2010) have been the most enthusiastically received of these, and the subject of much additional attention from the hacker community. However, the possibilities of the hardware are currently limited by the enforcement of uninspired mapping strategies, whereby the actions of the player are directly mirrored by his/her avatar on-screen. Yet if this literal translation is immediate and intuitive, it is very coarse and imprecise compared to the fine grain of control offered by joypads and joysticks. Furthermore, the philosophical implications of this are debatable. On the one hand, marketers have promoted the natural and intuitive qualities of the interaction (*Changed*, 2010), and it is true that some previously disinterested groups have been enticed into participation. On the other hand, the abstracted and idealised forms imparted are anything but natural. Their diversity smoothed over, users are transformed into digital versions of Le Corbusier's (2004) *Modular Man*. Such enforced universality is not only fundamentally incompatible with the notion of personal expression, but may actually exclude those whose bodies fall outside the manufacturer-imposed norm (quite the opposite of the designer's intention):

However, that experience, that "natural magic" is only available for bodies and players who have always been abstracted, universalized. Players who are raced, gendered, differently abled, differently sized will not find the Kinect so connecting. (Interestingly, the old school technologies of text-

based or keyboard-based VR [Virtual Reality] seems to be far more accommodating to different bodies and abilities.) (Changed, 2010)

In contrast to the rather staid (and arguably implicitly problematic) mappings currently adopted by video games designers, the designers of musical instruments and interfaces have long experimented with more adventurous mapping strategies (the simple one-to-one mappings found in acoustic musical instruments might be seen as a comparable point of departure). Thus, if the limitations of the mirroring paradigm of interaction are to be transcended, it may be interesting and beneficial to introduce one-to-many and many-to-one mappings into the gesture-controlled video games context. The latter would seem to have particularly interesting potential for multi-limb and multi-user interaction.

Further crossovers between digital musical instruments and other fields have been discussed by the author and colleagues elsewhere. These include the development of rhythmic skills and limb independence (Holland *et al.*, 2010; Bouwer, Dalglish and Holland, 2011a), interfaces for musical analysis and composition (Holland *et al.*, 2011; Bouwer, Dalglish and Holland, 2011b), and pervasive healthcare (van der Linden *et al.*, 2011). This material is omitted here for the sake of brevity, but that so much is still to be explored is surely an indication of the potential longevity of the subject matter.

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# Appendix A

## Portfolio Contents

### Early work:

- Loop (2004);
- The Interactive Pavilion 1 (2006) (with TMA Hellerau, Frieder Weiss, Daryl Georgiou and Leith Slater);
- The Interactive Pavilion 2 (2006) (with TMA Hellerau, Frieder Weiss, Daryl Georgiou and Leith Slater);
- Footfall (2006);
- Dream Machines Workshop (2008) (co-organiser).

### Scanners:

- Scanners Overview;
- Seeds demonstration (2010).

### mTable:

- mTable Overview;
- General:
  - Chapter 1 - Community Core Vision (CCV) overview;
  - Chapter 2 - CCV to Max.
- User study:
  - Chapter 1 - user 2 session 1 (Multi topography);

- Chapter 2 - user 2 session 2 (Multi topography);
- Chapter 3 - user 3 session 1 (Drift topography);
- Chapter 4 - user 3 session 2 (Drift topography).

### **iPad Topographies:**

- iPad Topographies Overview;
- User Study:
  - Chapter 1 - user 2 (Drone topography);
  - Chapter 2 - user 3 session 1 (Brennschluss topography);
  - Chapter 3 - user 3 session 2 (Drone topography);
  - Chapter 4 - user 5 (Drone topography);
  - Chapter 5 - MD playing the Drone topography.

### **ServoString:**

- ServoString Overview;
- Slideshow.

### **Vanishing Point:**

- Vanishing Point Overview;
- Slit-scan interface;
- Demonstration.

### **DelayNet:**

- DelayNet Overview;



- Demonstration.

**Eden3:**

- Eden3 Overview;
- Lab test at Compton (2008);
- Installation at the Headlands Arts Center, San Francisco (2009).

# Appendix B

## Questionnaire

For completion after participation in the user study. Please read and sign the consent form before completing this questionnaire.

There are 25 questions in total. Leave blank any questions that you do not wish to answer.

**Are you male or female?**

male

female

**How old are you on the present date?**

\_\_\_ years

**Which is the highest level at which you have received any formal music education?**

1 = none

2 = school

3 = post-16 (sixth form, college, etc.)

4 = undergraduate level

5 = post-graduate level

**How much prior experience of playing a musical instrument do you have?**

1 = 0-6 months

2 = 6 months-1 year

3 = 1-3 years

4 = 3-5 years

5 = 5-10 years

6 = more than 10 years

**Which musical instruments do you play (list all applicable)?**

(open text response)

**In which of the following contexts do you play the above instruments (if applicable)?**

1 = at home

2 = informally, with friends

3 = solo public performance

4 = group public performance

**Which styles of music do you play (if applicable)?**

(open text response)

**How exciting did you find playing the instrument?**

1 = very unexciting/boring

2 = neutral

3 = very exciting

**How satisfying did you find playing the instrument?**

1 = very unsatisfying

3 = neutral

5 = very satisfying

**How inspiring did you find playing the instrument?**

1 = very uninspiring

3 = neutral

5 = very inspiring

**How flowing was your experience of playing the instrument?**

1 = strongly disjointed

2 = disjointed, with occasional flow

3 = neutral (neither flowing nor disjointed)

4 = flowing, but occasionally disjointed

5 = strongly flowing

**How unfamiliar or alien did you find your experience of playing the instrument?**

1 = very unfamiliar

3 = neutral

5 = very familiar

**How direct was the perform-instrument interaction?**

1 = very indirect

3 = neutral

5 = very direct

**How quicky did the instrument respond to your (gestural) input?**

1 = very slowly

3 = neutral

5 = very quickly

**How precise did you find the instrument to be?**

1 = very imprecise

3 = neutral

5 = very precise

**How user-friendly was the instrument?**

1 = very unfriendly

3 = neutral

5 = very friendly

**How quickly did you progress in learning to play the instrument?**

1 = very slow

3 = neutral

5 = very rapid

**How intimate did you consider the performer-instrument relationship?**

1 = very intimate

3 = neutral

5 = very distant

**How pleasing did you consider the sound of the instrument?**

1 = very unpleasant

3 = neutral

5 = very pleasant

**How would you describe the sound of the instrument in terms of its texture?**

1 = very smooth

3 = neutral

5 = very rough

**How would you described the tonal colour (timbre) of the instrument?**

1 = very light

3 = neutral

5 = very dark

**How broad do you consider the musical possibilities of the instrument?**

1 = very narrow

3 = neutral

5 = very broad

**If given the opportunity, how likely would you be to play the instrument again in the future?**

1 = very unlikely

3 = neutral

5 = very likely

**Do you have any other comments?**

(open text response)

## Appendix C - Results

Appendix C - Results											
					1	2	3	4	5	6	7
DELAYNET		Name	Date	Duration	To which of the following racial or ethnic groups do you belong?	Are you male or female?	How old are you?	Which is the highest level at which you have received formal music education?	How much experience of playing musical instruments do you have?	Which musical instruments do you play (if applicable)?	In which of the following contexts do you play the above instruments (if applicable)?
session_ID											
1		anom	05/11/09	139	White	Male	26	2	3		At home
2		anom	05/11/09	41	White	Female	29	3	4		At home
3		anom	05/11/09	60	White	Male	18	4	6	2	At home, Informally with friends, Solo public performance, Group public performance
4		anom	05/11/09	62	White	Male	18	4	4	1	Group public performance
5		anom	06/11/09	101	Asian	Male	27	2	2	0	
6		anom	06/11/09	62	White	Female	55	1	1	0	
7		anom	06/11/09	102	White	Male	26	2	3	1	At home
8		anom	06/11/09	53	White	Male	23	4	5	1	At home, Informally with friends, Group public performance
9		anom	06/11/09	75	White	Male	20	4	6	2	At home, Solo public performance, Group public performance
10		anom	06/11/09	64	White	Male	45	2	3	0	
11		anom	06/11/09	75	White	Male	19	4	5	1	At home, Informally with friends, Group public performance
			mean	75.81818182			27.81818182	2.9090909091	3.81818182	0.9090909091	
			std dev	27.9600364156			11.8221671602	2.0570379089	1.6011359604	0.7006490497	
VANISHING POINT											
Session ID											
1		anom	24/03/09	79	White	Male	19	4	4	Vocals (1)	At home, Informally with friends, Solo public performance, Group public performance
2		anom	24/03/09	88	White	Male	40	2	6	oboe, flute (2)	At home, Group public performance
3		anom	24/03/09	63	White	Male	36	5	6	guitar, bass, synthesizer (3)	At home, Informally with friends, Solo public performance, Group public performance
4		anom	24/03/09	69	White	Male	29	3	3	Guitar (1)	At home
5		anom	24/03/09	84	White	Female	55	1	1	None (0)	
6		anom	24/03/09	61	White	Male	31	3	4	Trumpet (1)	At home, Group public performance
			mean	74			35	3	4	1.333 instruments played on average (8 / 6)	
			std dev	11.2782977439			12.1161049847	1.4142135624	1.8973665961		
IPAD TOPOLOGIES											
Session ID	Topology No.										
1	1	anom	11/06/10	53	Other	Male	42	2	3	keyboard and organ (2)	At home, Informally with friends
2	3	anom	11/06/10	67	White	Male	36	3	3	guitar mandolin and lute (2)	At home, Informally with friends
3	5	anom	11/06/10	62	White	Male	24	1	1		
4	1	anom	11/06/10	56	White	Male	29	1	4	Turntable (1)	Solo public performance
5	2	anom	11/06/10	71	White	Male	22	1	1		
6	2	anom	12/06/10	69	White	Male	68	5	6	Self-designed instruments, piano (2)	At home, Solo public performance, Group public performance
7	1+5	anom	12/06/10	98	White	Male	21	3	3	six and twelve string guitar (1)	At home, Informally with friends, Solo public performance, Group public performance
8	4	anom	12/06/10	63	White	Male	30	3	3	bass guitar (1)	At home
			mean	67.375			34	2.375	3		
			std dev	13.8247965627			15.4827092498	1.4078859532	1.6035674515		
mTABLE											
Session ID	Topology No.										
1	2	anom	17/08/09	85	White	Female	31	3	3	accordion banjo and bass (3)	At home, Informally with friends
2	2	anom	17/08/09	42	White	Female	29	4	6	Violin (1)	At home, Informally with friends, Solo public performance, Group public performance
3	1	anom	17/08/09	68	White	Male	45	2	1	None (0)	
4	3	anom	17/08/09	90	White	Male	25	2	2	Guitar (1)	At home
5	3	anom	24/08/09	64	Asian	Female	28	2	1	None (0)	
6	2	anom	24/08/09	77	White	Male	53	4			
7	1	anom	24/08/09	69	White	Male	53	1	1	None (0)	
			mean	70.7142857143			37.7142857143	2.5714285714	2.3333333333	0.833 instruments played on average (5 / 6)	
			std dev	15.7872763718			12.2299398433	1.133893419	1.9663841605		



# Appendix D

## The mLibrary

**4xWavetable.maxpat** - four wavetable oscillators grouped for greater simplicity of control.

**16xGroove1.maxpat** - a group of sixteen sound file playback objects reading from a common buffer.

**Cannon1.maxpat** - for each bang received, pushes out the next value from a randomly generated list.

**Casio2.pd** - collective control of four Casio-style oscillators based on a patch by Louis Gorenfeld.

**Comparator1.maxpat** - a simple comparator for audio signals.

**DateTime.pd** – gets date and time information at regular intervals.

**DelayFM2.maxpat** - frequency modulation of a signal by delayed and pitch-shifted copies of itself.

**DualFMslider.maxpat** - simple FM synthesis, the parameters of which are controlled by sliders.

**FeedbackComb1.maxpat** - tuned comb filter with feedback, version 1.

**FeedbackComb2.maxpat** - tuned comb filter with feedback, version 2.

**FeedbackComb3.maxpat** - tuned comb filter with feedback, version 3.

**FMnew2.pd** - FM synthesis in Pd.

**FMnew3.pd** - FM synthesis in Pd.

**FMnew4.pd** - FM synthesis in Pd.

**InterpolationWT1.maxpat** - interpolation space for 2-D wavetable oscillator.

**InvertSignal1.maxpat** - a simple way to invert audio signals.

**Looper** - a four track looping patch in Pd.

**MatrixMixer1** - 4x4 matrix mixer for audio signals.

**MatrixMixer4x4.pd** - 4x4 matrix mixer for audio signals.

**Movement1.maxpat** - simple movement detection patch for video.

**MultiString3.maxpat** - mutual influence of string physical models.

**MultiString4.maxpat** - mutual influence of string physical models.

**PD1.maxpat** - Casio-style Phase Distortion Synthesis, a port of a Pd patch by Louis Gorenfeld.

**PLL2.maxpat** - attempt at a Phase-Locked Loop (PLL) patch.

**PLL3.maxpat** - collective control of multiple PLLs.

**Power1.maxpat** - arbitrarily transforms matrix data created by a multislider.

**RandomBitStream1.maxpat** - applies logical operators to an audio stream.

**Ratchet1.maxpat** - an implementation of a ratchet sequencer.

**ScaleList.maxpat** - scales a list.

**Slew1.maxpat** - two different types of slew limiter.

**StringScaleOffset1.maxpat** - simple patch to offset a list by a given amount.

**SyncOscX4.maxpat** - four synchronised oscillators.

**WaveDraw1.maxpat** - draw a waveform into a buffer 1.

**WaveDraw2.maxpat** - draw a waveform into a buffer 2.

**WaveMorph2.maxpat** - morph between waveforms 1.

**WaveMorph3.maxpat** - morph between waveforms 2.